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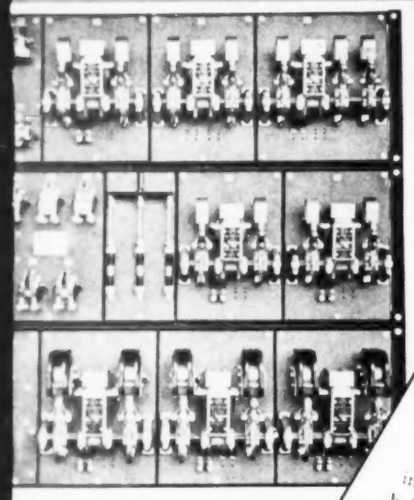

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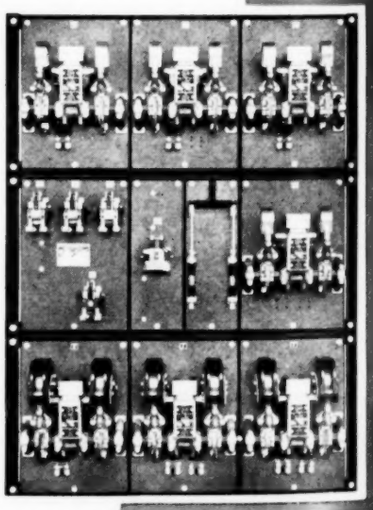

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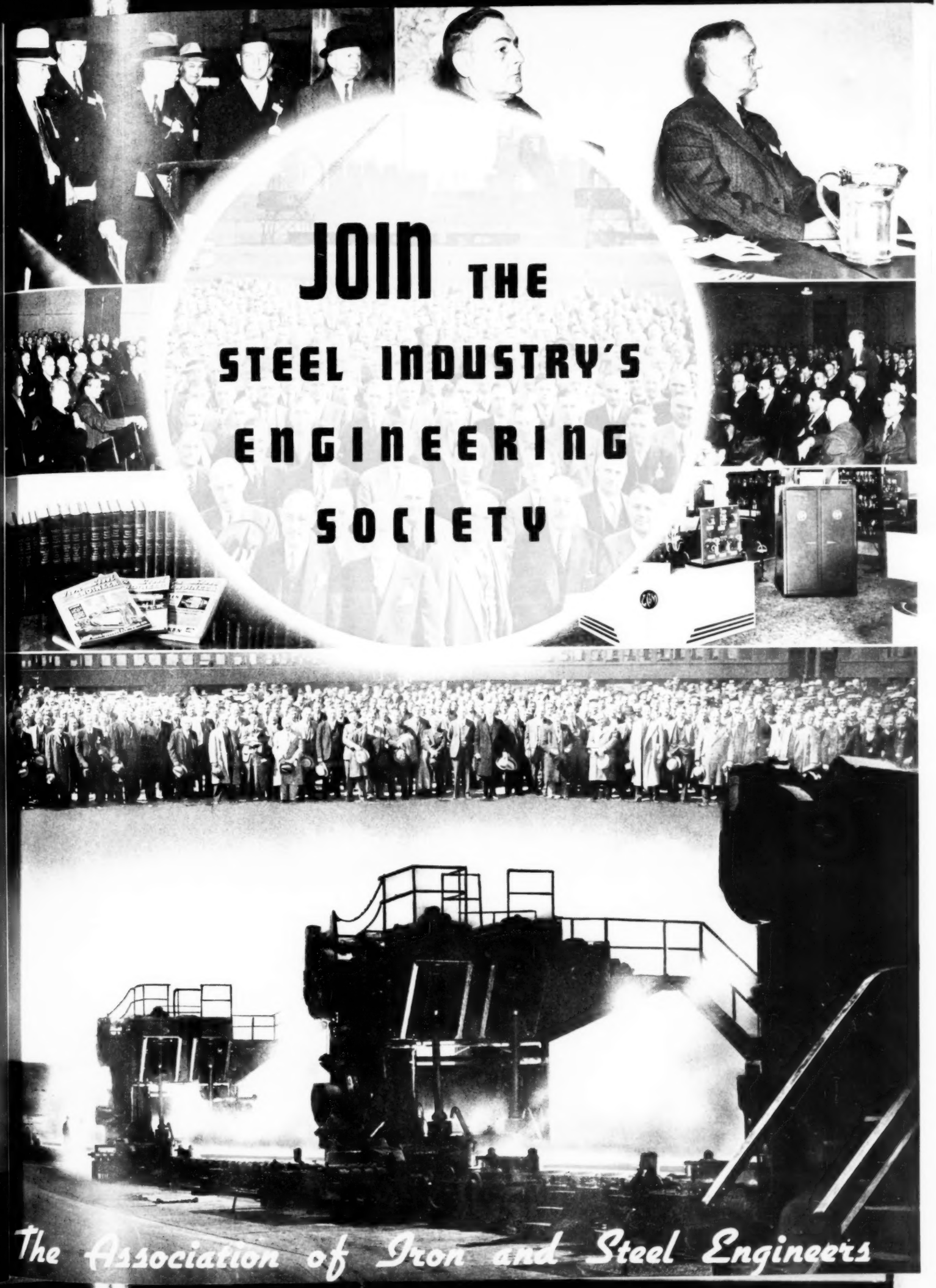
JOIN THE
STEEL INDUSTRY'S
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SOCIETY
The Association of Iron and Steel Engineers

FOREWORD

The Association of Iron and Steel Engineers, formerly known as the Association of Iron and Steel Electrical Engineers, is an organization composed of the executive, engineering, and operating personnel of the iron and steel industry, as well as representatives of manufacturers of steel mill equipment and supplies. The Association was founded in 1907, when at an informal gathering of twenty-eight electrical and mechanical engineers to inspect a special exhibit of electrical apparatus for use in iron and steel plants, Mr. James Farrington, then electrical superintendent of the Labelle Iron Works, Steubenville, Ohio, suggested the formation of a national organization of the men in charge of the electrical departments of the iron and steel industry, to meet at stated intervals to discuss the subjects of common interest to electrical engineers and superintendents in their industry. The Association is now starting its 32nd year of service to the industry with greatly amplified activities, now embracing all divisions of steel mill engineering and operation. It is recognized as the steel industry's most comprehensive engineering society.

To accomplish its purpose of advancing the technical and engineering phases of the production and processing of iron and steel, the Association maintains a program of activities designed to bring before its members the new developments in engineering and operating practices of the industry. The Association is carefully directed by the men actively concerned with, and responsible for the solving of, the problems of the iron and steel industry. Planning and coordination of the program by these men assures its value and interest.

MEETINGS

Technical meetings are periodically held in each of the six district sections, located in Pittsburgh, Philadelphia, Cleveland, Detroit, Chicago, and Birmingham. A Spring Engineering Conference and an Annual Convention are held each year. At all of these meetings, papers are presented by leading authorities on the various phases of design, construction, operation or maintenance of steel plants and plant equipment. The papers are also thrown open for discussion by anyone desiring to do so. In this way it is possible to review the subject from all angles and to assure its complete coverage. Approximately sixty papers are thus presented each year.

PUBLICATIONS

The papers and discussions presented at the various meetings, together with many other special features and articles, are published in the official organ of the Association, the IRON AND STEEL ENGINEER, which is recognized as the outstanding publication serving the operating and engineering personnel of the iron and steel industry. With the editorial matter selected and arranged by men familiar with steel plant problems, its value is assured. At the end of each year, the proceedings are put into book form, making a permanent and useful reference volume.

Almost every phase of steel plant operation and engineering has been discussed in the technical meetings of the Association.

The "Iron and Steel Engineer", the monthly publication, is authoritative and informative, and is the foremost journal covering the iron and steel industry.

More than 100 inspection trips to various plants have been conducted by the Association.

The Iron and Steel Exposition affords an opportunity to inspect the latest progress in plant equipment.

Approximately 1600 papers have been presented in the more than 500 meetings held since the Association was founded.

The yearbook contains all the papers published throughout the year in the "Iron and Steel Engineer", and is a valuable reference book.

Attendance at individual inspection trips has ranged as high as 1250 members and guests.

Thousands of steel men take advantage of the Iron and Steel Exposition to keep abreast of modern developments.

IRON AND STEEL EXPOSITION

The Iron and Steel Exposition, held each year in conjunction with the annual Convention, is an exhibit of the latest developments and progress in steel plant equipment and supplies by the various manufacturers serving the industry. During the past twenty years this branch of the Association's activities has grown to be of great value to both steel men and equipment men, affording a mutual opportunity to discuss problems and practices.

INSPECTION TRIPS

Each year a number of group inspection trips are made through various steel plants where new improvements have been made. This opportunity to inspect other plants and see other equipment and practices is of great value, leading to a broader perspective in dealing with individual problems. Attendance at individual trips has ranged as high as 1250 members and guests.

ACHIEVEMENTS

The Association of Iron and Steel Engineers has carried on a program which has developed the original nucleus into an international organization with members in twenty-one foreign countries. It has been a guiding factor in the advancement of engineering in the steel industries. Through technical papers, exhibits of apparatus and personal contacts, it has broadened the viewpoint and ability of members. It has carried out standardization programs which have been of great assistance to the industry. It was the leader in establishing the safety movement, out of which has evolved the National Safety Council. It has taken an important part in the development of modern mill equipment. It is currently sponsoring educational projects in each of its district sections, designed to further the knowledge of individuals in the industry.

ADVANTAGES

From this brief outline can be seen the fact that the entire scope of activities of the Association are planned and coordinated toward a common end—the improvement of its members, and therefore, the improvement of the many processes entering into the manufacture of iron and steel, through the interchange of ideas and experience with men interested in the same problems. The Association fulfills a definite need created by the size and complexity of the steel industry, which is so constituted as to demand close relation and cooperation between the various branches of engineering.

If you are employed by a steel producing corporation in an executive, operating or engineering capacity, if you

are interested in the problems of the steel industry, you owe it to yourself and to your company to keep abreast of the latest changes, the developments in design, the new processes, the modern methods. It is by affiliation with and active participation in an organization whose sole purpose is the solution of the steel industry's technical and engineering problems that this can best be done. If you desire to profit from these opportunities, or to obtain full benefit of meeting and associating with the acknowledged leaders in this field, you should be identified with the Association of Iron and Steel Engineers.

MEMBERSHIP PRIVILEGES

Membership entitles one to the official publications of the Association of Iron and Steel Engineers, including the monthly issues of the IRON AND STEEL ENGINEER and the yearly transactions, as well as the privilege of attending and participating in all section meetings in Birmingham, Chicago, Cleveland, Detroit, Philadelphia and Pittsburgh, the Spring Engineering Conference, the Annual Convention, the Iron and Steel Exposition, and the scheduled inspection trips to various steel plants.

The advantages offered by full participation in Association activities, as enumerated in this folder, should not be overlooked by anyone associated or interested in the iron and steel industry.

Membership falls principally into two classifications, as follows:—

Active, which includes persons actively identified with, or having responsible charge of technical, engineering or supervisory work in the iron and steel or allied industries.

Associate, which includes persons actively identified with a company supplying equipment, material, or service to the iron and steel or allied industries.

Membership dues are $10.00 a year plus an initiation fee of $10.00. Application for membership should be made to the nearest district secretary:—

Birger Thele—c/o Tennessee Coal, Iron and Railroad Company, Pratt City Station, Birmingham, Alabama.

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DESIGN *and* OPERATION *of* A *Modern* BLAST FURNACE

By J. C. BARRETT

Carnegie-Illinois Steel Corp.

YOUNGSTOWN, OHIO

Presented before the A. I. & S. E. Annual Convention, Cleveland, O., September 27, 28, 29, 30, 1938

▲ TO discuss the design and operation of a modern blast furnace it is necessary that we resort to some of the earlier history and learn how the modern blast furnace was developed, in connection with which I will not go back further than the furnace that made 50 or more tons per day. James Gayley of Braddock, Pennsylvania says that the Struthers furnace near Youngstown, Ohio, which had a 9 ft. hearth, 16 ft. bosh and 55 ft. height, and used raw coal as fuel, is one which in 1870-71 produced 1600 to 1642 tons in a month, or 50 to 55 tons per day; and in 1876 this furnace made 2032 tons in a month or an average of 67 tons per day.

In delving into the transactions of American Institute of Mining Engineers, I find there were no furnaces recorded as making over 50 tons per day except the Struthers furnace of above date. Gayley in his paper on "The Development of American Blast Furnaces With Reference to Large Yield", read before the American Institute of Mining Engineers and The British Journal of the Iron and Steel Institute in 1890, states that the Isabella furnace, located at Pittsburgh had a daily output of 76 tons in 1876 and the Lucy furnace, with 9 ft. hearth, 20 ft. bosh, 20 ft. height of bosh, angle of bosh 75 degrees and 16 ft. stock line, had a monthly output of 3286 tons in 1878. In one week this furnace made 821 tons or 117 tons per day, with a coke rate of 2865 lbs. per ton of iron.

According to Birkinbine in American Institute of Mining Engineers in 1884, there were 676 blast furnaces in this country. These are shown in Table I.

It will be noted from the above figures that they were not running 50 per cent of capacity.

For comparison with the above, the reported number of blast furnaces in 1935 was 235 coke furnaces with an annual capacity of 50,845,731 gross tons, and 5 charcoal furnaces with an annnual capacity of 134,500 gross tons. The estimated production for 1935 was 21,200,000 gross tons.

The modern blast furnace and the operation of same no doubt began with the building of furnaces at Braddock, Pennsylvania in 1879-80 by Julian Kennedy.

TABLE I

No. Furnaces	Reported Capacity per Year	Average Yearly Capacity per Fce.	Total Actual Annual Production
	Net Tons	Net Tons	Net Tons
234 Charcoal	1,330,000	5,680	458,418
221 Anthracite	3,074,082	13,900	1,586,453
221 Bituminous	5,067,100	22,900	2,544,742
676	9,471,182	14,011 (Av)	4,589,613 or, 4,097,000 Gross Tons

Furnace "A" was blown in January 4th, 1880, and had the following dimensions:

Hearth	8′—6″
Diameter of bosh	13′—0″
Height of bosh	23′—0″
Angle of bosh	84 degrees
Diameter of stock line	10′—0″
Diameter of bell	7′—0″
Height of furnace	65′—0″

This furnace made 2762 tons in March of that year, averaging 89 tons per day.

In April 1880, "B" furnace was blown in and its dimensions were as follows:

Diameter of hearth	11′—0″
Diameter of bosh	20′—0″
Height of bosh	27′—0″
Angle of bosh	80 degrees
Diameter of stock line	17′—0″
Diameter of bell	12′—0″
Height of furnace	80′—0″

The production in October of 1880 was 4722 tons or an average of 152 tons per day.

Designation of Furnace	Year in Which Fce. Commenced Blast	Total Output From Blast	—In First 12 Months—		
			Output	Average Daily Output	Average Coke Consumption
Isabella	1876	117,575	28,000	76 tons	3000 lbs.
Lucy No. 2	1878	92,128	33,552	91 "	2850 "
Edgar Thomson "A"	1880			71 "	2400 "
" " "B"	1880	112,000	48,179	132 "	2859 "
" " "D"	1882	90,317	65,947	180 "	2570 "
" " "C"	1885	118,000	64,998	178 "	2677 "
" " "D"	1885	150,374	74,475	204 "	2250 "
" " "C"	1887	203,050	72,554	198 "	2230 "
" " "F"	1886	224,795	88,940	244 "	2150 "
" " "F"	1889		113,000	310 "	1920 "

Above is a table from Gayley's paper in transactions of the year 1890 of the American Institute of Mining Engineers:

In the transactions of the British Iron and Steel Institute in 1887 E. C. Potter gave an account of four furnaces built at South Chicago, Nos. 5, 6, 7 and 8. They were 75′ high, 9′ diameter hearth, 21′ diameter bosh, 27′3″ height of bosh, angle of bosh 76 degrees, stock line 15′, diameter of bell 9′. One furnace No. 5 was blown in, March 26th, 1881, just a year from the time the ground was broken for the foundation. The furnaces made about 1000 tons per week with a coke consumption of 2800 lbs. per ton of iron. Another furnace followed in August, 1881 doing about the same work. None of these furnaces ran over 2 years 7 months, after which they were relined to new lines. The bosh was reduced from 21′ to 20′ diameter, the hearth changed from 9′ to 11′ diameter, the angle of bosh made 80½ degrees, the bell left at 9′ diameter, the diameter of stock line made 15′ 4″, and the height of bosh raised to 29′—6″ above tuyeres. After relining, No. 5 furnace was blown in in March 1884. The others followed the remodeled lines and made from 5000 to 6000 tons per month or about 200 tons per day.

The Edgar Thomson furnace "F" was built in 1885-1886, with a hearth diameter of 11′, diameter of bosh 23′, height of bosh 22′, angle of bosh 75 degrees, diameter of stock line 16′, diameter of bell 12′, height 80′. The average monthly output for 5 months was 8150 tons or 270 tons per day with a coke consumption of 1980 lbs. per ton of iron. According to the table given by Gayley the tonnage for the lining was 224,795 tons and the average coke consumption was 2068 lbs. per ton of iron. In 1894 Edgar Thomson furnace "H" appeared with a 13′ hearth, a 20′ bosh, 15′ height of bosh, 75 degree angle bosh, 16′ stock line, 89′ height of furnace, batter of inwall .48″ per foot and a production of 400 tons per day. In 1900 "E" appeared with a 14′ hearth, 22′ bosh, 14′—4″ height of bosh, 72½ degree angle of bosh, 15′ stock line, 88′—3″ height of furnace, .809″ per foot batter of inwall. This furnace was able to produce 500 tons per day.

Ohio Works furnaces No. 1 and No. 2 were built in 1899 with hearth 15′, bosh 23′, height of bosh 15′—8″, angle of bosh 75 degrees 40 minutes, stock line 17′, bell 12′, inwall batter .535″ per foot, height of furnace 105′.

No. 3 furnace as a new furnace was blown in 1901 with a 16′ hearth, 23′ bosh, 10′—9″ height of bosh, 72 degree 4 minute angle of bosh, batter of inwall .635″ per foot, 16′ stock line, 12′ bell, 105′ height of furnace. The second lining on this No. 3 furnace had a 16′—9″ hearth, 22′ bosh, 9′—3″ height of bosh, 74 degree 4 minute angle of bosh, .325″ per foot inwall batter, 18′ stock line, 9′—3¼″ bell with a Killeen distributor. The No. 4 furnace was a new furnace and was blown in Sept. 6, 1904 with a 16′ hearth, 23′ bosh, 13′—8″ height of bosh, 75 degree 40 minute angle of bosh, .568″ per foot batter of inwall, 16′ stock line, 11′ bell, 90′ height of furnace. Nos. 5 and 6 furnaces were put in blast in 1909 with 17′ hearth, 23′ bosh, 14′ height of bosh, 77 degree 54 minute angle of bosh, .831″ per foot inwall batter, 17′ stock line, 12′—4″ bell with McDonald distributor, 95′ height of furnace.

The figures in Table 2 giving the size of hearth, bosh angle, height, etc., show an interesting development of the blast furnace for 50 to 55 years. The trying out of different dimensions and different angles and different distributors cannot be all told in the table presented. The Edgar Thomson and Ohio furnaces have been used largely to show the development to the present modern blast furnace. The furnace in 1880 had a hearth 8′—6″, which has now been increased to 23′ to 28′ diameter or more. The height of bosh has varied from 9′ to 30′ and the angle of the bosh from 72 to 86 degrees or more. The height of the furnace varied from 65′ to 105′. A great deal of the development of our modern blast furnaces has been arrived at by "cut and try" method, but the science and principles we learn from Bell in his "Chemical Phenomenon of Iron Smelting" do not change, and we were just groping around for the best way to adopt them. But the modern blast furnace grew over this period of 50 to 55 years by the indefatigable or persistent work of many able men. Ohio No. 3 furnace, it was thought in 1904, was not doing as well as expected and in the midst of discussion on height of furnaces, it was cut

TABLE 2

Furnace	Blown In	Blown Out	Diam. Hearth	Diam. Bosh	Height Bosh	Angle of Bosh	Batter of Inwall	Diam. Stockline	Diam. Bell	Height Furnace	Distributor
Struthers	1871		9′–0″	16′–0″						55′–0″	
Duquesne			14′–6″	22′–0″	13′–10″	74°	.68″	17′–0″	12′–6″	100′–0″	
South 5	1881		9′–0″	21′–0″	27′–3″	76°		15′–0″	9′–0″	75′–0″	
South 5	1884		11′–0″	20′–0″	29′–6″	80°–30′		15′–4″	9′–0″	75′–0″	
South 7	1908		17′–0″	22′–9″	15′–1″	78°	.75″	17′–9″		94′–0″	
South 4	1914		17′–8″	22′–0″	14′–6″	80°	.75″	17′–0″		90′–0″	
South 4	1926		18′–6″	23′–6″	14′–0″	80°–10′	1.00″	17′–0″	13′–0″	90′–0″	
E.T.-A	Jan. 1880		8′–6″	13′–0″	20′–6″	84°		10′–0″	7′–0″	65′–0″	
E.T.-B	Apr. 1880	2 Yr.–5 Mo.	11′–0″	20′–0″	27′–1″	80°		17′–0″	12′–0″	80′–0″	Double Bell
E.T.-C	Feb. 1885		10′–0″	20′–0″	20′–4″	79°		16′–3″	10′–6″	80′–0″	
E.T.-D	1882	17 Mo.	11′–6″	23′–0″	30′–0″	79°		17′–0″	11′–0″	80′–0″	
E.T.-D	Sept. 1885		11′–0″	22′–0″	29′–9″	79°		15′–10″	11′–6″	80′–0″	
E.T.-C	Mar. 1887		11′–0″	21′–0″	20′–6″	76°		15′–0″	10′–3″	80′–0″	
E.T.-F	Oct. 1886	1889	11′–0″	23′–0″	22′–0″	75°		16′–0″	12′–0″	80′–0″	
E.T.-F	Sept. 1889		11′–0″	22′–0″	22′–0″	75°		15′–6″	12′–0″	80′–0″	
E.T.-H	1894		13′–0″	20′–0″	15′–0″	75°	.481″	16′–0″		89′–0″	
E.T.-E	1900		14′–0″	22′–0″	14′–4″	72°–30′	.809″	15′–0″		88′–0″	
E.T.-K	1902		15′–6″	22′–0″	13′–9″	75°	.75″	16′–0″		88′–3″	
O.W. 1	2/14/00	4/30/03	15′–0″	23′–0″	15′–8″	75°–40′	.535″	17′–0″	12′–0″	105′–0″	None
O.W. 1	7/24/03	3/20/05	16′–0″	23′–0″	13′–8 7/16″	75°–40′	.433″	18′–0″	11′–0″	105′–0″	
O.W. 1 P	5/ 2/05	11/26/07	16′–0″	23′–0″	13′–8 7/16″	75°–40′	.718″	16′–6″	11′–0″	105′–0″	McDonald
O.W. 1	5/27/08	5/30/11	17′–0″	23′–0″	13′–8 7/16″	77°–37′– 9″	.743″	16′–6″	11′–0″	105′–0″	McDonald
O.W. 1 P	7/21/11	10/19/14	15′–0″	23′–0″	13′–8 7/16″	77°–37′– 9″	.74″	16′–6″	11′–0″	105–0″	McDonald
O.W. 1	3/ 9/15	4/10/20	17′–6″	23′–0″	13′–8 7/16″	78°–37′–20″	.72″	16′–6″	12′–0″	105′–0″	McDonald
O.W. 1	1/ 3/25	10/31/29	19′–9″	24′–6″	14′–0″	80°	.84″	17′–6″	13′–4″	105′–0″	None—New Fee.
O.W. 1	2/13/37	12/31/37	23′–0″	26′–0″	9′–0″	80°–32′–16″	.84″	19′–0″	14′–0″	105′–0″	McKee
O.W. 2	6/ 6/00	8/17/03	15′–0″	23′–0″	15′–8″	75°–40′	.535″	17′–0″	12′–0″	105′–0″	None
O.W. 2	1/ 5/04	6/27/05	16′–0″	23′–0″	13′–8 7/16″	75°–40′	.435″	18′–0″	11′–0″	105′–0″	None
O.W. 2 P	8/19/05	6/ 4/08	16′–0″	23′–0″	13′–8 7/16″	75°–40′	.718″	16′–6″	11′–0″	105′–0″	McDonald
O.W. 2	11/28/08	11/26/13	17′–0″	23′–0″	13′–8 7/16″	77°–37′– 9″	.743″	16′–6″	11′–0″	105′–0″	McDonald
O.W. 2	7/22/14	2/24/21	17′–0″	22′–0″	12′–0″	78°–13′–54″	.694″	16′–6″	12′–1″	105′–0″	McDonald
O.W. 2	11/17/21	6/25/27	18′–6″	23′–6″	14′–3″	80°–2′	.83″	17′–0″	13′–0″	105′–6″	None
O.W. 2	5/20/29		25′–0″	28′–0″	10′–0″	80°–30′	1.062″	19′–0″	14′–0″	104′–6″	McKee
O.W. 3	3/29/01	7/22/02	16′–0″	23′–0″	10′–9 3/4″	72°–4′	.635″	16′–0″	12′–0″	105′–0″	None
O.W. 3	9/24/02	12/19/03	16′–9″	22′–0″	9′–3 1/4″	74°–11′	.325	18′–0″	12′–0″	105′–0″	Killeen
O.W. 3	5/14/04	5/15/05	16′–0″	23′–0″	12′–9 7/16″	74°–41′– 8″	.794″	18′–0″	11′–0″	90′–0″	None –Cut to 90′–0″ –in 1904
O.W. 3 P	6/21/05	10/26/07	16′–6″	23′–0″	14′–0″	74°–41′– 8″	.879″	16′–0″	11′–0″	90′–0″	None
O.W. 3 P	1/27/08	2/26/10	16′–6″	23′–0″	14′–0″	77°– 8′–23″	.861″	17′–0″	12′–0″	90′–0″	None
O.W. 3	6/29/10	11/19/11	17′–0″	23′–0″	14′–0″	77°–54′–20″	.835″	16′–6″	12′–0″	90′–0″	None
O.W. 3 P	12/30/11	12/ 5/13	17′–0″	23′–0″	14′–0″	77°–54′–20″	.835″	16′–6″	11′–0″	90′–0″	None
O.W. 3	2/ 5/13	2/18/14	17′–0″	23′–0″	14′–0″	77°–54′–20″	.835″	16′–6″	12′–4″	90–0″	None
O.W. 3 P	1/14/16	2/ 3/16	17′–0″	23′–0″	14′–0″	77°–54′–20″	.835″	16′–6″	12′–4″	90′–0″	None
O.W. 3	7/13/19	5/25/25	18′–6″	23′–0″	13′–6″	80°–32′–15″	1.000″	16′–6″	13′–0″	89′–0″	None
O.W. 3	3/13/26	7/23/30	21′–6″	24′–6″	9′–0″	80°–32′–15″	.800″	17′–6″	13′–4″	106′–6″	None
O.W. 3	6/19/33	9/25/37	23′–6″	26′–6″	9′–0″	80°–32′–15″	.810″	19′–6″	14′–2″	106′–6″	McKee

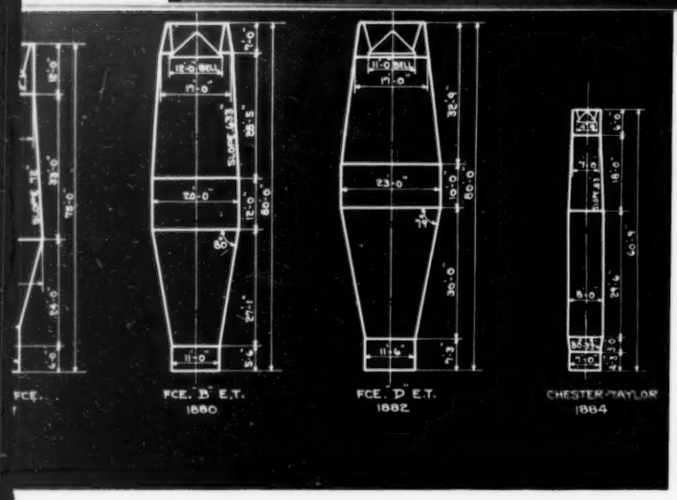


FIGURE 1—Early blast furnace lines show small hearths in comparison to the other proportions of the furnace.

down from 105′ to a 90′ furnace and when No. 4 was constructed it was made 90′. In building No. 5 and No. 6 furnaces the height was raised to 95′. Having had experience with all heights, when No. 3 furnace was rebuilt in 1925 it was made 105′ in height. The 90′ furnace has never been as satisfactory as the taller furnace.

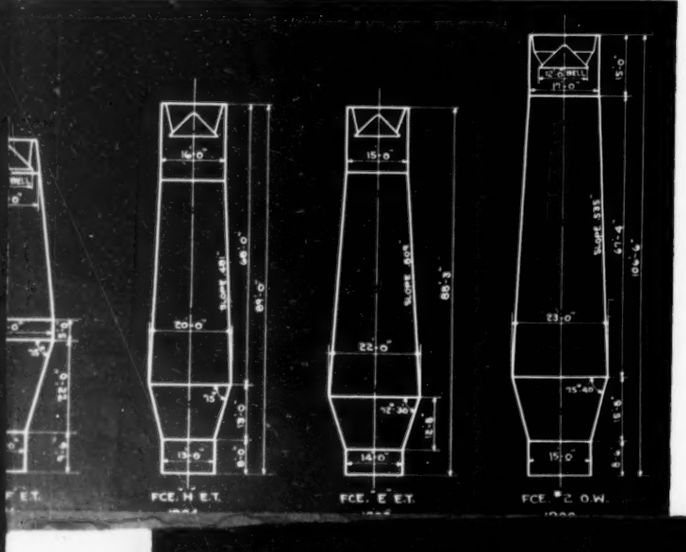
The modern blast furnace should be at least 100′ in height for best results, as this study would indicate, and I believe for efficiency the tall furnace is the best.

The hearth of the blast furnace is the receptacle to hold the molten metal and slag, and finish the refining operation, and it should be well constructed and well cooled; made of the best refractory and have at least 13′ of refractory bottom. The bottom of any good furnace hearth should not be laid in layers but bonded from top to bottom of the 13′ of brick as illustrated by Figure 4. If it is installed in layers, as soon as the erosion of the iron and slag goes through the layer the tendency of the balance of the layer is to float, which results in a larger salamander.

The tuyere section should be very substantial and so constructed that there is no crack or line through which cinder could find its way out.

The bosh should be very strong and properly cooled. There was much interest in the preservation or protection of the bosh, the first protection being a jacket made of wrought iron or steel, air or water cooled. Later a water cooled coil was put inside of the jacket. A person by the name of Hunt (American Institute of Mining Engineers Vol. 21), at the Crane Iron Works in 1877, used a cast iron plate with a coil or space for water, and placed in the wall flush with the outside of the wall. Kennedy then developed a plate with two spaces for water, made of copper, and placed close to the inside of the wall, the idea being that if the first space was lost the second would afford protection. In 1884 Cremer at Edgar Thomson used vertical hollow boxes on the outside. At Johnstown a bronze bosh cooling box was set in the wall. Then came the Scott cooling plate with which we are familiar. Gayley, whose paper gives this information, used a plate with a water way in the first half of the plate. The Scott plate is the one largely used, but it was originally made in such a manner that it gave trouble due to leaks where the plugs and anchors were used. It required good inspection and peening to overcome the seeping of the water through the walls of plate under pressure. The manufacturer of the plate has now improved it so as to make the plate without anchors and plugs.

FIGURE 2—Subsequent development brought a gradually increasing furnace height as well as greater hearth diameters.



You will note from Table 2, which shows the height of bosh as well as the angle of both that the extreme height is from 9′ to 30′ which on some of the early installations was almost half the height of the furnace. Ohio Works furnaces have varied from 15′—8″ to 9′—0″ and have now settled at 10′. The angles have varied from 72 to 86 degrees; 80 to 81 degrees is a very satisfactory angle. The diameter of the bosh is definitely related to hearth diameter, angle of bosh, and batter of inwall.

The establishment of proper lines in bosh and inwall for a good furnace has required a great deal of thought on the part of furnace managers. There is no doubt that much of the furnace trouble has been due to so many grades and qualities of coke and limestone; that is, the large and small pieces with dust or dirt. The chemist, to make an easy fusion in his crucible, wants the material real fine, so in a similar way the fine stone and dust helps to make an easy fusion, or begin the fusion in the blast furnace a little higher up. This makes it difficult to decide on what are good lines for smooth operation. I saw one furnace in the early days which was clogged up and would not move for 18 hours. They pulled 2 or 3 plates above the cinder notch just under the mantle, and found the bosh empty and no material at the end of the plate. With a 30 ft. rod they could not reach the other side of the bosh. Some plates were then pulled just opposite under the mantle showing a foot or more of material at the end of the plate and you would see across to the opposite hole. This let air into the bosh and cooled and contracted the arch which was above the mantle, and it dropped easily. This led us always to cool the furnace and let stand for a while when in that kind of trouble. As soon as it came down the furnace was ready to go ahead. These experiences are hard on the nerves. Coke made now is much cleaner and more uniform in size and quality; stone is better sized and well screened or washed, and ore is also graded. With improved conditions in stone and coke, better lines in the furnace, and possibly larger furnaces, we do not encounter this hanging condition.

Table 2 shows a great variety of slopes of the inwall or batter that have been tried. Naturally some batter of the wall is expected to ease the settling of the stock.

Some furnacemen are inclined to think a very slight batter is acceptable. It would be well to cite the experience with a straight or no bosh blast furnace by Tayler of Chester, New Jersey, American Institute of Mining Engineers, Vol. 12, page 498. This furnace, 60′ high with 7′ hearth, 8′ bosh, 7′ stockline, and 4′ bell (see Figure 1), operated only 16 days and was an utter failure. It would hang and was very difficult to move. Ohio Works has tried from .32″ per foot batter to 1 1/16″ per foot. I think that 1 1/16″ is the limit and am sure from our experience, that .80 to 1 1/16″ produces good working conditions. There has been a great variety in wall thickness, ranging from 9″ to 60″. The lining should be 36″ to 42″ thick and laid so as to just clear the rivet heads where there is no cooling, but laid tight against the shell where there is cooling. There should be some protection in the lining by cooling up to 25′ above the mantle. The lining should also be protected by 6′ of wearing plates at the stock line.

The modern furnace should produce at least 1,000,000 to 1,500,000 tons of pig iron per life of lining, whereas in the early days 250,000 tons or more was the life of a lining; in 1890 Gayley expected to get 450,000 tons. The brick manufacturers have developed a superior brick compared with that manufactured twenty-five years ago, with the result that today we get a very good quality and more uniform size of brick, which is of great importance as disintegration of the brick in the lining presented a bad condition. The ambition of a furnaceman is to get a good tonnage out of a lining, and the improvement of the brick and the protection above the mantle and at the stock line has been a great benefit to him. We certainly feel badly when we see a red spot on the side of the shell—the lining is gone.

The shell of the furnace stack should be made very substantial and strong, double riveted vertically and horizontally or welded. The columns which support the shell should have a very solid foundation and they should be arranged about the hearth so as to afford clearance around the tuyere zone.

The structure on the top of the furnace should be very substantial and so designed that as much equipment and counterweights as possible are placed on the ground or in the skip house. (See Figure 5.) The bell equipment, receiving hopper and a McKee revolving hopper, are essential. The revolving hopper should have a long throat and if possible should have some deflection in it to distribute the stock as it is received from the skip and deposited into the revolving hopper. The space between the small bell and big bell for a 25′ hearth furnace should be about 1400 cu. ft. The setting of the top of the furnace is a very particular job. In putting the parts of the top together, the bells and operating equipment must be hung so that everything is free and in the center of the furnace, as well as balanced, interlocked in operation, and timed.

The work of finishing the setting of the furnace top is done when the furnace is filled to about 30′ from the top. We go down to the stock and inspect conditions, and if it is found slightly irregular we level off and then with a charge or two at a time, go into the furnace and if necessary adjust the filling with the top.

The skip and skip bridge should not be attached to the furnace nor supported by the furnace. It should be independently supported, and very substantial. The

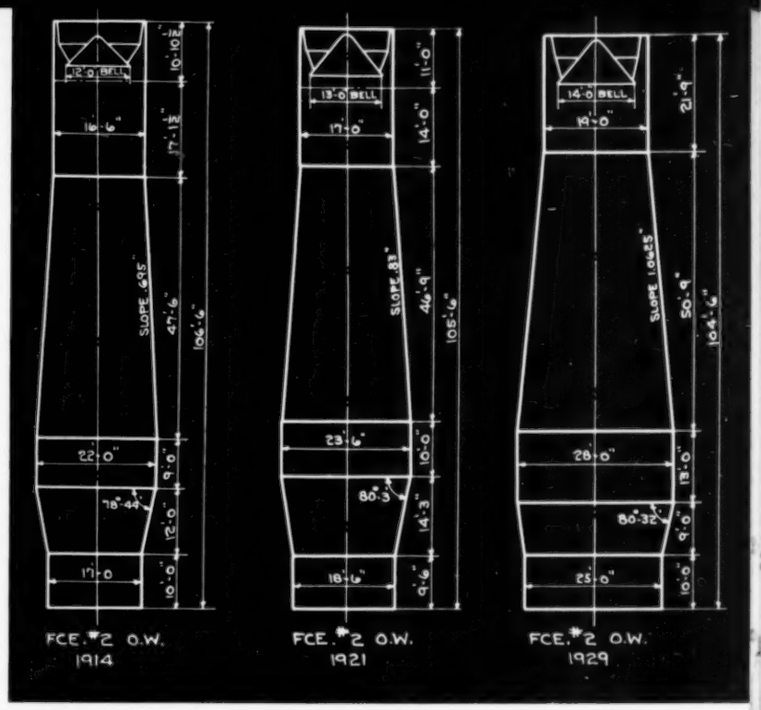


FIGURE 3—Recent progress has brought increased diameters in all sections of the furnace, with the height remaining stationary.

FIGURE 4—Blast furnace hearth brick work should not be laid in layers, but should be bonded from top to bottom.

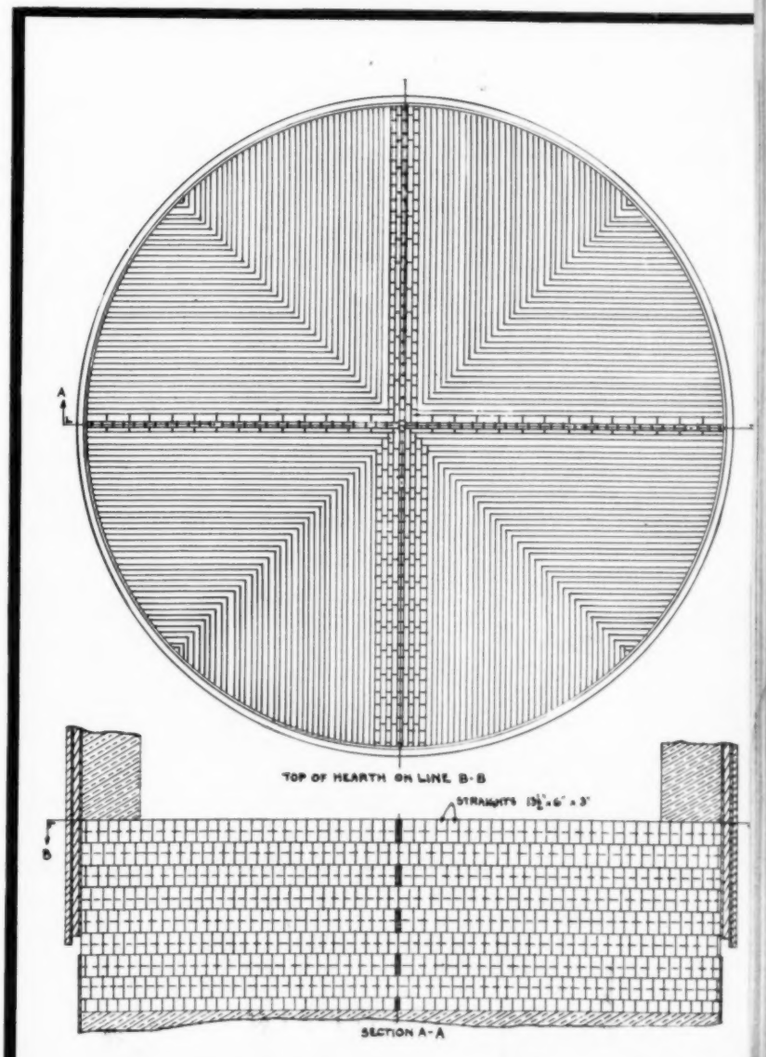
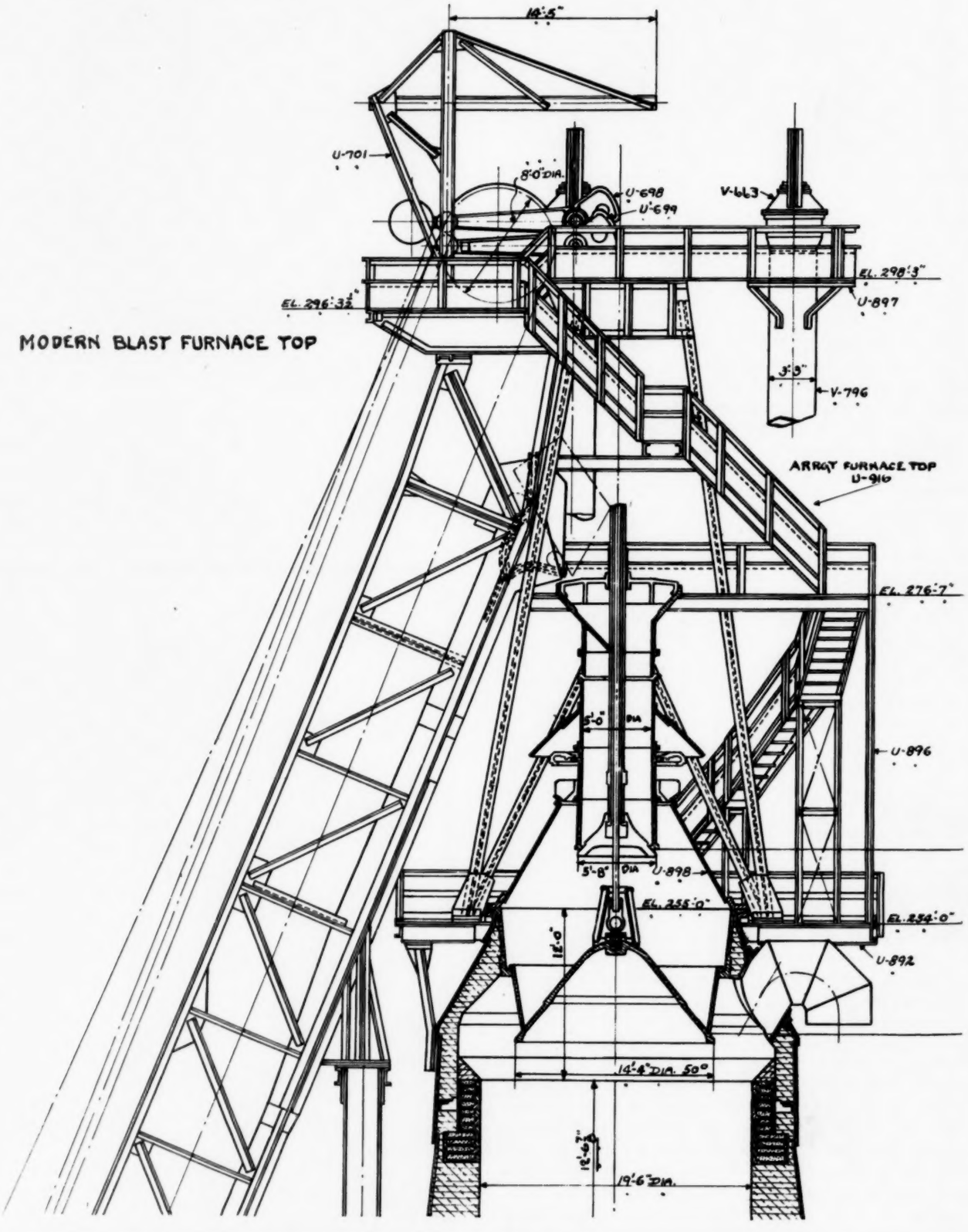


FIGURE 5—The furnace top should carry the minimum amount of equipment. The skip bridge should not be attached to or supported by the stack.



downcomers for the gas should be lined with brick, and at the points where there is an exceptional wear, should be lined with cast iron or steel. The openings from the furnace to the downcomers should be large, with no contraction.

The dust catchers should be at least 30′ in diameter and so constructed inside as to assist the settling of the dust. The gas should go to a gas washer of sufficient size to cool the gas and wash it to at least .15 grains of dust per cu. ft. The gas from the washers should receive secondary cleaning, preferably by electrical precipitators. I would suggest three precipitators in parallel with a total capacity of 120,000 cu. ft. per min. for a 1000-ton furnace to produce gas under .03 grains per cu. ft. dust contact. Three precipitators would allow cleaning one without too much overload being put on the other two, and would furnish good gas for 3 or 4 stoves as required for a total of 500,000 sq. ft. of heating surface. The waste gas from the stoves should have a temperature 250 to 300 degrees. The flue dust washed from gas should be caught in a commodious sump or Dorr thickener and handled at least expense.

The stoves, which should be very substantially built with double riveting, vertically and horizontally, or welded, should have the best burner, regulator and control equipment. The checkers should be of a type that each checker would rest on its own base, and not a basket weave type. The brick of the checker should be of the best material. A 1″ or 1¼″ checker is desirable.

For the stocking and charging equipment, enough bins should be provided for all raw materials, so designed as to permit free flow of the contents; that is, with a steep angle in the bottom of bin and no sharp corners. Chutes that will operate easily and require little poking should be provided so the operator can do the stock house work quickly and economically. The scale car should be very substantial, easy and safe to operate, and with a recording scale. Every provision should be made in the stock house so that one man can easily move the material for a 1000-ton furnace. The skip to transfer the material to the top should be large enough to move the material to the top with ease, and fast enough to hoist more than the furnace capacity.

The coke from bins should pass over screens to an automatic weighing bin from which it goes into the skip car. The automatic weighing bin should always be full, waiting to be emptied.

In preparing the furnace to go into blast, it is dried out thoroughly by use of dutch ovens (three if a large furnace) spaced equally about the furnace at tuyere holes. A crown of 4″ brick is built over a frame work just above the coolers with holes distributed around the edge of the crown to allow the burned gas to escape. The other tuyere openings are closed and the ovens are fired continuously for two weeks at least, and more if there is time. The top is closed and waste gas forced down to the dust catcher which is kept open.

To prepare the furnace for filling, remove the brick crown. Put 3 or 4 wheelbarrows of dry sand over the iron hole inside, bank it up and place some large coke around it. Place a carload or more of coke about the furnace floor and fill into the hearth by hand, up to the coolers. Place the tuyeres in the coolers, then put some small kindling wood, only two or three cart loads, back two or three feet and above the tuyeres, leaving a sort of nest before the end of tuyere in which you can place excelsior or cotton waste. Put brick in the tuyere to protect from fire while filling the furnace. The furnace is then filled from the top by use of the skip.

The filling unit for a large furnace should not be less than 20,000 lb. of coke (4 skips, 5000 lb. each), 50,000 lb. of ore, scale and sinter (2 or 3 skips), and 8000–10,000 lb. of stone (1 skip), or a total of about 80,000 lb.

First six or seven rounds of coke (20,000 lb. per round) are put in, followed by three more rounds of coke with enough stone to make a 50-50 slag. The next four or five rounds should each consist of one regular burden charge, of approximately 20,000 lb. of coke, 45,000 lb. of ore and 8,000 lb. of stone, accompanied by three blank charges (60,000 lb.) of coke, giving a ratio of ore to coke of about .55. The next four rounds are each made up of one regular burden charge with two extra coke charges (40,000 lb.), making an ore—coke ratio of .75. This is followed by fifteen rounds each composed of one regular burden charge accompanied by one extra coke charge (20,000 lb.), giving an ore—coke ratio of about .9. After this, two regular burden charges are used, followed by one extra coke charge, making a ratio of ore to coke of 1.5, for ten to fifteen rounds. The extra coke is gradually withdrawn until an ore—coke ratio of about 2. is obtained. The filling should be stopped at about 30 ft. from the top for inspection.

The above method of filling a furnace is simple, and avoids a continual changing of the burden. Thus, the burden can be set, and merely alternated with extra coke charges until the operating burden is reached.

At the bottom have the iron hole plugged and the mud gun up against it. The blow pipes are put up after the inspection in the top and the filling are completed and the top closed. No blow pipes are put up while inspecting inside and adjusting the filling. When ready to light the blast furnace, with a long pipe pour one quart of torch oil into the waste in the nose of each tuyere. With the blowing engines running (if the furnace is connected to other furnaces), open the gas main and let gas fill all connections and the furnace for a few minutes, which will remove all air from the dust catcher and top through the bleeder. If not connected to another furnace in operation, open all of the top. Then open the hot blast valve and cold blast valve and as soon as a little blast appears at the furnace, put hot rods into each tuyere and slowly raise the snort valve. The furnace is lit. It is not well to go over 1000 or 1100 degrees blast temperature at the start, as too high a blast temperature can hang the furnace. Start the furnace with 25,000 cu. ft. of air per minute and add 1000 cu. ft. per minute each hour up to 45,000 per minute. Then add wind slowly until you reach the place where the furnace works best. Within 15 minutes after the blast of 25,000 cu. ft. is on, the bleeder can be closed and the gas put into the mains for use in boilers or any other service. In about 15 hours, or after a good ladle of slag is taken from the cinder notch, start to open the iron hole with a drill at a fairly low angle. After the drill goes through the clay use an air hose and blow out some of the sand, and if necessary use a burner on same angle as the drill was used. The first cast

should be very hot. Put the furnace in the regular casting time and order.

This filling and starting of a blast furnace has been worked out over several years, and is the most satisfactory in my experience, and so simple as it is not necessary to change the burden every few rounds.

For years furnacemen filled the furnace with charges in layers. I believe the general practice at present is to fill the furnace with a mixed charge. Ohio Works has never used layer filling but rather the mixed filling and large charges. In this form usually 1 skip of ore is placed on the big bell, then two skips of coke, one skip of stone, one skip of ore, and two skips of coke, or a total of seven skips—about 80,000 to 85,000 lb. Sometimes the ore density for one ore is different from another and we may have to divide the ore into 3 skips instead of 2 skips. This makes eight skips on the big bell but the same weight. The arrangement on the big bell will require, at times, some thought. At times the furnacemen may want to invert the charge for a certain number of rounds—coke on the big bell first. The ore and stone should be arranged, especially when you use three skips of ore, so that one half of the ore will be mixed with each two skips of coke. This gives the best results for efficiency.

Fifteen feet from the top of the furnace to the stock is the mark for a full furnace and it would be five feet to the stock from the closed bell. Automatic gauge rods should be used to keep the operator informed as to the depth of stock, and he must keep it at the full point for good work. The charge dropped from the big bell should measure between 3′ and 4′ rise in the furnace, so that a charge should be on the big bell and lowered when the stock line has descended to 18′. It may be found through observation and study that 16′ or 17′ may be the mark for a full furnace with the best results, in which case the operator should not fill until the gauge rod shows 19′ or 20′. The form the stock takes in a filled furnace is an inverted cone and naturally the large coke, ore and stone would roll to the center of the furnace more readily than the fine material. The volume in a 19′ diameter furnace for one foot depth is 283 cu. ft. The regular charge for a 20,000 lb. coke unit made up of 7 skips is about 1000 cu. ft. Therefore it can easily be seen that the volume of stock dropped at once would spread over the whole area and carry some small ore with it. An extreme illustration would be to drop one skip of material into the furnace; it would lay close to the wall and not much would carry towards the center. If filled with this small unit, I am afraid

FIGURE 6—Distribution of stock in furnace containing a movable deflector ring.

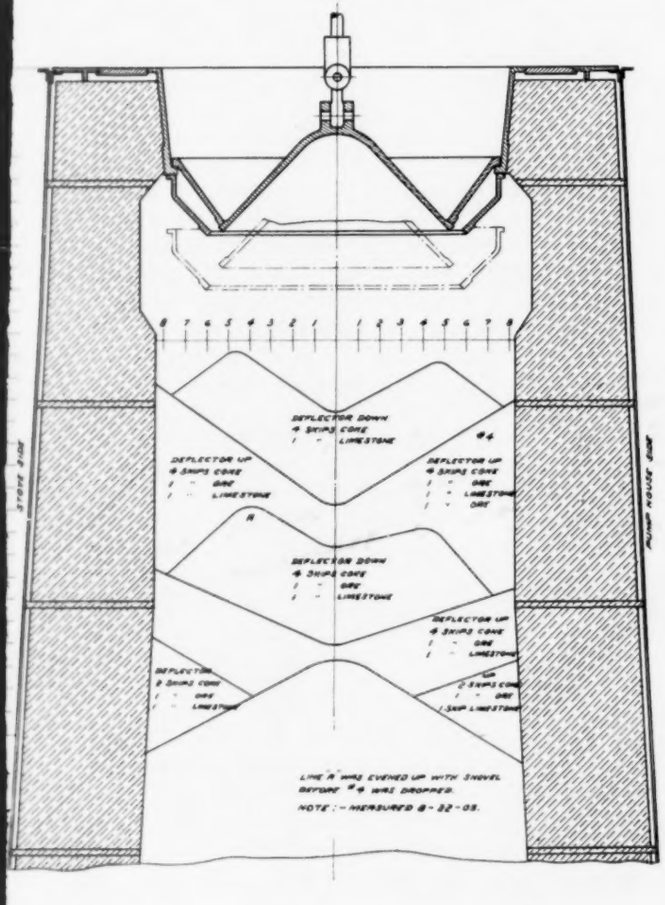
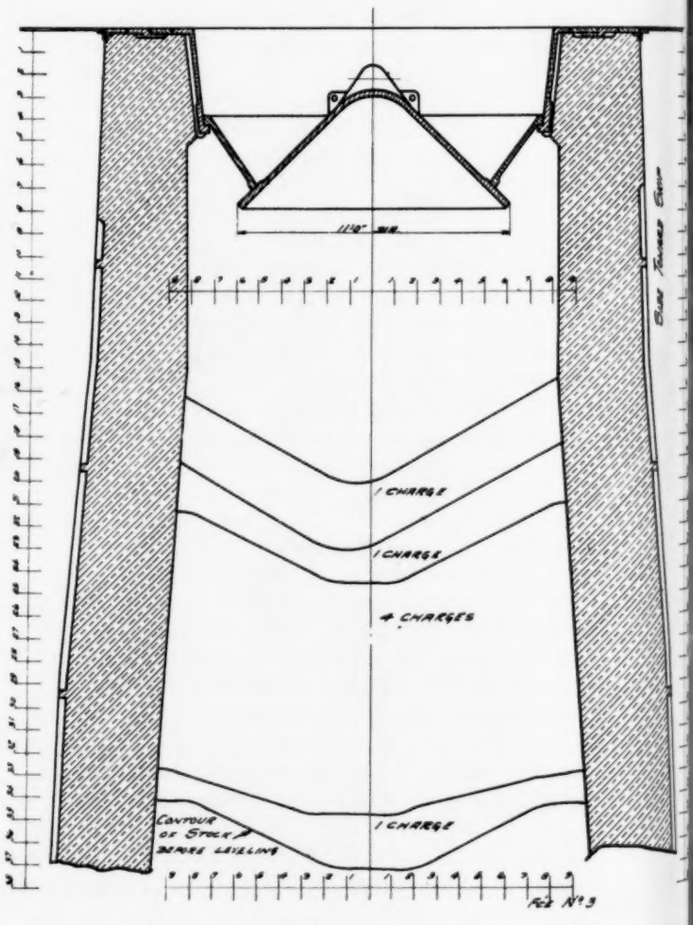


FIGURE 7—Distribution of stock in furnace with conventional top.



it would be a poor operation. Unless the charge is large the center of the furnace becomes a flume of coke and does no work, and, I would say, produces low flue dust. This thought gave rise to the McDonald distributor by which material is deposited more towards the center of the furnace. (See distribution in Figures 6 and 7.) The attainment of good distribution has been the ambition of all furnacemen so they could obtain a good working furnace, good coke consumption and good life on the furnace lining.

The following enumerates many of the devices developed to assist in improving the distribution in the blast furnace:

The Killeen, Neeland, Brown, Baker-Newman,

Ohio No. 2 Furnace
19′ Stock Line
Plane 1.—4 Ft. Below Stockline

Distance from Inwall	Percent CO	Percent CO_2	Ratio	Temp.
0′	23	17.9	1.3	565
1′	21.8	19	1.1	541
2′	21.7	19.2	1.1	480
3′	22.2	18.9	1.2	415
4′	22.6	18.7	1.2	321
5′	23.4	18.2	1.3	222
6′	24.3	17.4	1.4	294
7′	25.8	16.1	1.4	428
8′	26.0	15.6	1.7	494
9′	25.4	16.8	1.8	511
9′—6″	25.6	15.8	1.7	555
Top gas	25.3	15.6	1.62	

Blast Pressure	20.5 lbs.
Blast Temperature	971°
Top Temperature	406°
Lbs. Coke	1790
Tons per Day	935

South No. 4 Furnace
17′ Stock Line
Plane 1.—4 Ft. Below Stockline

Distance from Inwall	Percent CO	Percent CO_2	Ratio	Temp.
0′	29.9	10.7	2.7	448
1′	29.5	10.8	2.7	520
2′	26.7	13.3	2.0	588
3′	21.1	17.1	1.2	860
4′	24.5	16.2	1.5	920
5′	24.2	16.5	1.5	888
6′	24.8	15.6	1.6	1250
7′	26.4	15.3	1.7	1284
8′	33.6	7.9	4.2	1320
8′—6″	35.3	6.9	5.1	
Top gas	24.8	14.7	1.69	

Plane 2.—8 Ft. Below Plane 1

0′	31.2	8.8		1429
1′	28.2	12.0		1095
2′	24.6	16.6		980
3′	22.8	17.3		1212
4′	23.0	17.7		1580
5′	23.4	17.8		1604
6′	23.1	17.6		1642
7′	24.9	16.1		1605
8′—2″	23.7	16.6		1670

Plane 3.—18 Ft. 6 In. Below Plane 1

0′	35.3	3.2		1587
1′	28.1	11.6		1540
2′	24.4	15.3		1352
3′	25.2	14.6		1620
4′	26.1	14.6		1674
5′	25.6	14.4		1635
6′	28.2	13.2		1675
7′	27.4	11.9		1755
8′—1″	29.5	10.8		1796

Lbs. Coke	1889
Tons per Day About	700

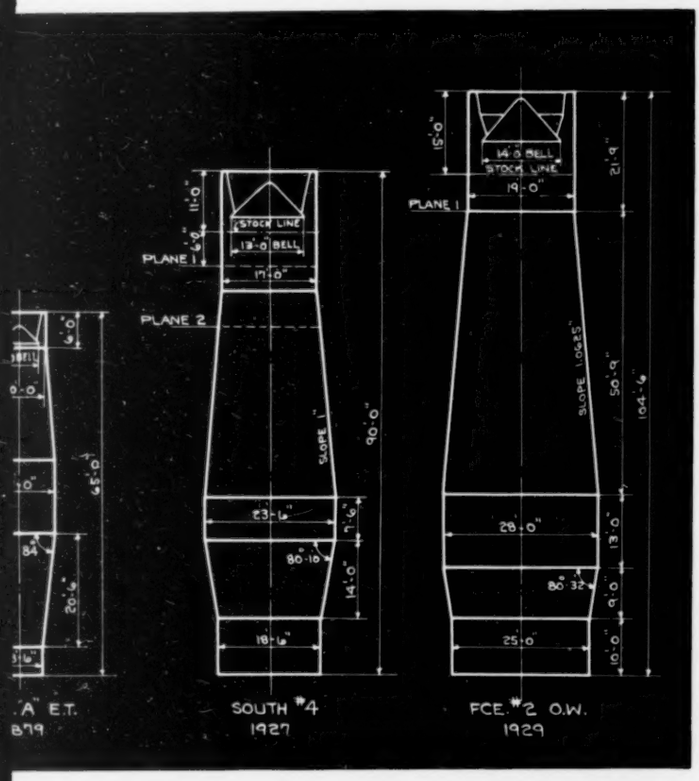


FIGURE 8—This comparison shows the progress of fifty years, during which daily production increased from 100 tons to 1000 tons.

Roberts, Kennedy, Slick, McDonald, and McKee distributors, an inverted cone under the little bell, all of which have had their day and gone except the McKee.

No modern blast furnace could operate efficiently without the McKee revolving hopper—it is a distributor, but I do not think it is a cure-all for troubles in furnace operation. The ratio between the area of big bell and the area of the stock line has very much to do with distribution, and has been a case of "cut and try" with observation to get the best results. It was the opinion that 2 ft. clearance between the bell and wall was the proper relation. A 12 ft. bell and 16 ft. stock line was considered a good working furnace, but an 11′—9″ bell on a 16 ft. stock line would do better. From my experience the ratio of big bell area to stock line area which gives the best results is 1.82 to 1.85, preferably 1.84. Distribution with this ratio will show very definitely that it is about right with a large charge by the gas analyses from furnace wall to center of furnace. Very definitely the size of the charge of material put into the furnace effects the distribution. Kinney in his study of the blast furnace in the Bureau of Mines technical paper No. 442, "The Blast Furnace Stock Column", gives the best information on the workings of the furnace since the days of Lowthian Bell. Kinney made tests on No. 4 furnace at South Works, Illinois Steel Company. These tests were made on four planes from the lining to the center of the furnace. Similar tests were made on Ohio Works No. 2 furnace in the same position as on plane 1, about 4 ft. below the stock line, of South No. 4. The average tests are compared in Table 3.

South No. 4 had a burden of 24,000 lb. of ore and 9,000 lb. coke, showing about 135 charges per day. Ohio No. 2 had a burden of about 50,000 lb. of ore and 20,000 lb. of coke, with about 80 charges per day. In the day of Bell, the ratio of CO to CO_2 was 2 to 1. The ratio for Ohio No. 2 is less than 1.5 to 1 by samples from the test below the stockline, but the top gas was 1.6 to 1. The South No. 4 ratio for top gas is 1.69 to 1. The ratio of bell area and stock line area for Ohio No. 2 is 1.84 and the ratio for South No. 4 was 1.71. The tests from Ohio No. 2 show very uniform analysis each foot across the top, while the tests from South No. 4 are certainly not uniform; the CO ranging from 21.1 to 35.3 per cent and CO_2 from 6.9 to 17.1 per cent. This is an indication of very good distribution on Ohio No. 2 and confirms the ratio of bell and stock line and the use of large charge. The coke rate for Ohio No. 2 was 1790 lb. and for South 1889 lb. In my years of observation I know of a small blast furnace with a 10 ft. bell and 13′—6″ stock line which gave wonderful results, and in this case the ratio for bell and stock line areas was 1.82.

As an example of good results in operation ,I would cite Ohio No. 2 with its history, using a 25′ hearth, 28.5′ bosh, 10′ height of bosh, 80½ degree angle of bosh, batter or slope of inwall 1 1/16″ per ft., stock line 19′, bell 14′, ratio of bell to stockline 1.84. After making 1,262,000 tons we were obliged on account of business conditions to blow it out. We repaired the furnace by patching the lining above the mantle and the stock line at an expense of about $20,000. On account of the furnace wall being worn at the stock line and some distance below the stock line, we trued up by making the stock line 19′—6″ diameter and changed the bell to 14′—4″ diameter. The furnace now has made a total tonnage of 2,400,000 on a coke consumption of 1785 lb. per ton of iron, with no excess scrap and no sinter. The furnace is still doing well, producing about 1,000 tons per day, and the iron is very hot physically, with a very low percentage of off-sulphur casts.

There has been some discussion on the amount of flue dust produced by the large charge against the amount produced by the small charge. If the whole area of the furnace is working, it will no doubt make more dust than if the central area has a small amount of ore and acts as a coke flume. You will note on the table of tests of the two furnaces how rich South No. 4 is in CO and low in CO_2, whereas the gases are quite uniform on Ohio No. 2. It depends upon what you base efficiency, low coke or low dust. The dust is recoverable and saved, but when we burn unnecessary coke it can never be recovered.

The beneficiation of materials for the furnace is of great importance, and results in better efficiency. The fine ores and flue dust and scale can be sintered to an advantage, and the large ore can be crushed. The coke can be made from properly mixed coals, and the stone prepared to the proper size and cleanliness. In a case where you can pick raw materials it is possible to get exceptional results. From my experience I must recite an incident that some furnacemen remember. It is pertinent to this question. Frazier at Warren, Ohio did some exceptional work in tonnage that many questioned could be done. But after the examination of the materials he used, his sieve tests revealed the secret.

I asked the Ohio management to allow me to select from our ore yard as near as possible similar ores to burden the furnace. The request was granted. The results of the furnace operation corresponded to the Warren furnace. We used the select ores for a month and then returned to the regular burden for a month and the next month used the select material again. Both months with select material gave exceptional tonnage. When we returned to the regular burden between the select months and after, the production returned to the normal rate. Our friend Frazier led us also in the matter of fanning the blast furnace, when the plant is long in pig production. This method of operation is better than banking for short periods, as it keeps the furnace hot. While fanning, some of the tuyeres should be plugged. Fanning can be done very successfully. The rate of operating the modern furnace depends on close observation of all conditions. There is a certain rate that seems to be best for the individual furnace—the economical point for coke and flue dust production. There is a point of overblowing, which reduces efficiency. This question has been brought out and written about as far back as Gayley's time in the eighties when he showed by his practice that there is an efficient rate.

The blast furnace operation is a continuous one and the best results are obtained with as few stops as possible. Casting should be performed if possible without taking off the blast, or at a suitable pressure. A well equipped mud gun is essential, and saves time and stops.

For good results there should be but few changes in the burden. Use high blast heat with some reserve capacity in stoves. Large ladles and short runners are essential to avoid increasing the furnace crew. The modern large furnace and its products can be handled with ease by the same crew that handled a 500 ton furnace if provisions are made for it. This cuts the operating cost.

There is a study of the size and length of tuyere in connection with the wind blown for the best results and one can only get best results by watching the operation at the tuyere, the filling operations, and the gas at the top of the furnace. The dust catcher should have a place for escaping gas to be observed by the crew at the furnace. By watching the reaction at all these places and keeping a record of same, one can get the pulse of each furnace. The success of good operation and practice with a loyal organization, certainly depends on constant vigilance.

The whole process is to serve the steel department with a good product and to help them make good steel. The evolution of the blast furnace from the 9′ hearth to the 25′ hearth and from the production of 100 tons per day to 1000 tons per day in 50 years is history. (See Figure 8.) It has been cooperation between men and between plants. One trying this, another trying that, until the modern furnace has a better foundation, a better hearth, better shell, better coke, better top, better lines, better stone, better brick, more uniform ore, better stoves, better heat, better gas for stoves, better stock yard facilities, better filling, better record of operation, and better iron.

DISCUSSION

PRESENTED BY

J. H. SLATER, Superintendent Blast Furnaces' and Coke Ovens, Republic Steel Corporation, Cleveland, Ohio.

D. P. CROMWELL, Superintendent Blast Furnaces, Youngstown Sheet and Tube Company, Campbell, Ohio.

B. E. PHENEGER, General Superintendent, Central Furnaces and Docks and Coke Works, American Steel and Wire Company, Cleveland, Ohio.

A. G. McKEE, President, Arthur G. McKee and Company, Cleveland, Ohio.

F. B. QUIGLEY, General Superintendent, Carnegie-Illinois Steel Corporation, Farrell, Pennsylvania.

W. S. UNGER, Staff Engineer, Carnegie-Illinois Steel Corporation, Pittsburgh, Pennsylvania.

J. H. SLATER: The early history and evolution of the blast furnace with particular regard to American practice is of real value and Mr. Barrett has in an interesting way shown how, in 60 years, we have progressed from a furnace making 70 tons per day to one capable of producing 1000 tons. With the paper in general I am in hearty accord. Naturally, there are some points on which my opinion does not coincide with Mr. Barrett's.

My first objection is to brick lined downcomers. Wearing plates, in my opinion, are sufficient and unlined downcomers can be much smaller than when brick lined. There is some additional advantage in lower gas velocities, due to greater cooling of the gases. The next point of difference is in the size of stove checker which Mr. Barrett advocates. In my opinion, a one-inch checker is entirely too small to be practical—in fact, I would not want to see anything less than a two-inch checker.

With regard to drying out and blowing in procedure, there are a number of differences which are really more a matter of personal preference and quite minor in importance. To my way of thinking, the two easiest things connected with blast furnacing are blowing them in and blowing them out. Operating successfully is the real problem.

One of the very big points established in Mr. Barrett's paper, I think, is the necessity of using a large charge when operating a 1000 ton furnace. This closes up the center of the stock column, and thereby forces the gases to work the entire cross section of the furnace. The CO-CO^2 ratios mentioned by Mr. Barrett as obtained at the Ohio Works are quite re-

markable—particularly as the furnace was on full wind. As he says, it is indicative of good distribution and proper ratio of bell diameter to top area.

In the matter of beneficiation of materials, Mr. Barrett touches on sintering. This subject is not new, but in my opinion, we have only scratched the surface. I believe that in the next five years we will all do a great deal more sintering of fine ores—thus cutting down flue dust production and increasing iron tonnage. We have all learned a great deal in the past eight years on the subject of over-blowing blast furnaces. However, most of this will no doubt be forgotten with the first drive for tonnage. The most efficient blast furnace I know of is one built for 1000 tons a day and operated at the rate of 750. It will however be difficult to sell this idea to the management when they need iron.

D. P. Cromwell: Mr. Barrett is to be congratulated for his fine description of the "Modern Blast Furnace". As the Ohio Works was the earliest large plant at Youngstown, many of their ideas filtered into the design, operation and construction of the Youngstown Sheet and Tube Company's Plant, which was built in 1908.

McKee tops are now being installed as rapidly as rebuilds come along, as at Ohio Works, and the results so far well justify their use. Several new designs have been produced, such as the Boynton, Crock and Juengling, but so far I do not know of any results from their use.

The largest furnace at Campbell Works is 95′ high, 21′ hearth, bosh 9′ high and 24′ 3″ diameter, bell 13′ 6″, stockline 18′ 6″ and batter .821″. The bell to stockline ratio on this furnace is 1.88.

For the first six months of operation on this furnace a large round was charged, similar to Ohio Works No. 2, and this furnace did not work so well. The round was gradually cut down to one skip ore and one skip coke for half the charge. Stone was added to the second half so that the past year and a half the standard filling has been ore-coke-dump-ore-stone-coke-dump. Total dust production is 60 lb., coke rate is under 1800 lb., with a normal production of 825 tons net iron per day. The only difference in design that is pertinent to this furnace is in the angle of the large bell, which is 53 degrees. The gas composition on this furnace runs 15 per cent CO_2 and 24.5 per cent CO, or a ratio of 1.63. Gas samples at the center of the furnace show high in CO_2 (17 per cent), which indicates that the center of this furnace is not a gas flume.

I do not believe that the problem of gas distribution in the large top furnaces has been by any means solved, as such important items as bell speed, angle, and depth of stock line show marked results in gas flow in the top section of the furnace. Also the problem of peripheral gas flow as attacked by Mr. Johnson at Inland will warrant watching in the large top furnace. At Youngstown Sheet and Tube Company we have done some work on the gas flow in the lower section of the furnace, which I do not believe can be governed completely by the appearance at the tuyeres. Thermocouples tell part of the story, but I believe in Germany, where they have been driven to higher efficiency due to raw material deficiencies, they have studied the gas flow from the tuyeres up and have profited handsomely from their efforts. The reports on their use of elliptical and "mouth" tuyeres indicate that for their raw materials they have made tremendous coke and dust savings.

Mr. Barrett's scheme on blowing in a furnace is certainly simple and novel. Possibly the only objections to such a method is the scouring tendency of brick that is produced by the use of coke blanks, and their use should, I believe, be discouraged as much as possible during regular operation.

Raw materials are already a serious problem in this country, and Mr. Barrett's statement regarding coke size is quite true. At the Sheet and Tube we have used as much as 75 per cent minus 1¾″ coke on a furnace for 60 days with good results, blowing 50,000 cu. ft. per min. of wind. This coke was, of course, well cleaned and passed over a 1″ screen. The silica-alumina ratio in ores is steadily going higher and a problem will have to be solved in the face of the demand for lower sulphur iron. Possibly this will lead to the treatment of iron with alkalies or the steel man will have to remove sulphur in his furnace at a greater cost. Sintering of fine ores has been very beneficial in some plants and merits considerable thought, and the furnaceman of today must be able to produce, either by change in design to afford better practice, or by knowing more about the inside working of the present furnace, and how to change the variables he has to work with, the same results, even at lower cost than at present.

B. E. Pheneger: Many of the changes and practices in blast furnace design and practice were brought about with the help of Mr. Barrett's study, good judgment, co-operation with other operators and long years of experience and faithful application to the art. While design and dimensions had much to do with the increased tonnages obtained from furnaces, the improvement of furnace fuel played a very important part in smoother operation with faster driving and greater tonnages.

From the beginning of the so-called modern furnace practice slag control has played an important part in successful production of good iron at low coke rates. However, the scientific knowledge of slag control was advanced very rapidly in this country by the excellent work of Prof. Richard S. McCaffery and his associates at the University of Wisconsin. This knowledge has stimulated interest so generally that blast furnaces are now operated at higher efficiencies.

There is still a difference of opinion amongst furnace operators as to the necessity or advisability of placing cooling plates in the stack lining. There are arguments for both opinions when referring to furnaces making ordinary basic and bessemer iron for steel works use, but there should be, without question, stack cooling plates to a height of at least forty feet above the mantle in furnaces making merchant pig iron of all kinds and specifications.

Mr. Barrett mentions the setting of the furnace top after the furnace is filled and adjusting the top to correct filling imperfections. I am also speaking of it to emphasize the importance of having the top closely

adjusted that the filling can be satisfactorily done, and with a compensating device on the big bell rod it can be so maintained.

When preparing the iron hole for blowing-in the furnace, I prefer the method, after having used it successfully many times, of inserting and packing a four-inch pipe in the tapping hole and allowing gas to blow through it and burn in the main trough until the pipe is plugged solid and tight by a slag formation. This forms a safe and easily drilled stopping. At no time has difficulty been encountered in opening the hole for the first cast.

While blowing-in a furnace I consider it good practice to keep the dust catchers filled with steam as a safety measure and they may later be flushed with gas from another connecting furnace before bringing down the gas from the new furnace. Analyses should be run frequently on the gas from the furnace being blown-in to determine when the highly explosive gases are no longer coming off and the time when the gas can be brought down in perfect safety.

The beneficiation of coals and ores has produced better fuel and raw materials with the result that very low coke rates have been obtained. One plant without scrap operates at about 1400 lb. on iron from basic to foundry. There is no doubt that lower ash and sulphur in coke promotes better practice and product. Care at the mines will produce better coal at little or no extra mining cost. One excellent example of the value of ore beneficiation is that described by J. T. Whiting, vice president of the Alan Wood Steel Company, in his recent paper on "Microscopic and Petrographic Studies of Blast Furnace Materials", presented before the General Meeting of American Iron and Steel Institute, May 26th, 1938. Another excellent example is the practice obtained at the Provo Furnace of the Columbia Steel Corporation, where the coke practice has been considerably reduced by crushing, sizing and sintering of their hard ores.

The sintering of fines from Mesaba ores to be used in large percentages with the regular ores has the possibility of accomplishing much good. This practice should result in smoother operation with better product, higher tonnages, lower coke rates and, consequently, better costs.

The weighing or skipping of coke has been a subject of much discussion; some who can weigh the coke want to skip it and vice versa. Central Furnaces has both methods and both have their advantages. In either case, compensation must be made for moisture and coke size.

The practice of fanning the furnace is not only successful for short periods in place of banking but also for long periods where certain tonnages of hot metal are wanted at intervals or when iron can be sold direct from production.

One subject now attracting much attention is the removal of sulphur from iron to improve it for the making of grades of open hearth steel requiring very low sulphur. The removal can be done in the blast furnace or in the ladle by additions. The problem which confronts everyone is—can the blast furnace advantageously do this or should external desulphurization be practiced?

Another subject in which I am much interested can well be mentioned in discussion; that is—control of moisture in the furnace blast. Consideration was given to drying the blast as early as 1853 by Prideaux in "Economy in Fuel". About 1890 Gayley began his experiments with mechanical refrigeration to cool the air to precipitate moisture. The operation proved too costly for the benefits derived and moisture removal received a serious setback. At that time, and immediately following, improvements in furnace design and raw materials over-shadowed the results to be obtained from moisture removal. The subject is again being studied by blast furnace operators and equipment manufacturers who are applying modern methods of atmospheric control to furnace blast.

In view of the decided trend toward more exacting and closer specifications for irons both for foundry and steel making purposes, it would appear that moisture control of the blast offers greater possibilities now than formerly; especially with regard to uniform operation. Without moisture control, a heat safety factor must be carried to compensate for rapid fluctuations in moisture content of the blast. With control, most of that reserve heat can be used to take care of a heavier burden.

Last, but by no means least, I call attention to the marked improvement in the practice of safety around furnaces with the great humanitarian and economic results.

A. G. McKee: Considering Mr. Barrett's paper, as it shows the progress from fifty tons to a thousand or more, and coincident with that progress in capacity of production, an increase in efficiency, in the quality of the product, and in the safety to the operators, the remarkable progress indicated is a truly wonderful result of the cooperation between the different plants and the different people.

Mr. Barrett has been in the field all his life and has contributed very largely to the improved results that have been obtained. The development of blast furnace lines shows a trial-and-error progress that was mostly error until recently. The quality of materials and the preparation of materials for the furnace have made marked progress.

I want to mention also Mr. Barrett's very unique experience in studying the matter of the height of the furnace. On the first furnaces at the Ohio Works I think he was wrong both times on the height. The first furnaces I think were 106½ feet from the top platform. I was on the drawing board when those drawings were made, and I had a most interesting experience in working out the lines, which were much discussed and were figured all the way from 100 to 110 feet. Finally, my old friend, Tom McDonald, somewhat in disgust, said, "Well, we will split the difference," and he split it not at 105 but at 106½.

Mr. McDonald was a curious and most interesting autocrat, and his results were generally good. The 106½ ft. height was too much of a problem for that day, and the results were not as good as expected, so they dropped back to 90, and then they gradually worked back up to 105 feet in height, and their going back to that figure very clearly evidences their belief and decision that that is the best height, at least unless they should go higher. I think one of the large

factors in the good results is the fact that in getting higher they have obtained greater volume of laboratory, in which the ore is reduced and prepared for its melting when it gets to the hearth. I very strongly advocate this increase in volume, not only by extra height but by even larger diameters at the top of the furnace.

Mr. Barrett has mentioned the top structure of the furnace and the use of a bridge entirely separate from the furnace. I think the construction of the furnace he showed today is very desirable and it is the only separately supported bridge design that I know of which doesn't put lateral strains on the top structure of the furnace due to the ropes controlling the movement of the bells and the hoist. I think it is a very good design, but still has the side pull due to the operation of the large and small bells which might be eliminated.

The matter of 1″ to 1¼″ checkers has been mentioned and is very interesting. Mr. Barrett's opinion is, I think, that small checkers are desirable, so long as you can keep back of your heating surface a sufficient volume of brick for the storage of the heat. The 1″ or 1¼″ is a matter of minor importance if we can get the required heating surface and the amount of brick back of the surface to give the best storage for heat.

The large capacity, large hopper, and the large charges undoubtedly have been very potent in Mr. Barrett's success in getting an almost ideal radial distribution of the stock and similar distribution of the gases passing up through the stock. This is a feature of furnace construction and operation which I think should be very well considered by others and, to get back to an old pet hobby of mine, I would imagine that the smaller clearance between the bell and stock line, even down to two feet, with the large charge probably would solve even better the radial distribution of the stock.

We never have had a large-top blast furnace with small bell clearance and with large volume charges, and I hope somebody will some day give a serious trial to that because I think it will still further improve the radial distribution of stock.

F. B. QUIGLEY: If I may, I would like to give just two instances which show that blast furnace men have to change their ideas about how things should be done. I remember the first big furnace blown in at Youngstown. In the old days, if you remember, they would start out with about 20,000 cu. ft. per min. of blast and then you would raise it 1000 cu. ft. per min. every 24 hours, until you got up to 45,000 or 50,000, or wherever you were going.

I believe one of the ideas in connection with that was that you had to impregnate the surface of the brick with carbon in order that the brick lining would last. Otherwise you would burn it out in a short time.

The first big furnace that was blown in at Youngstown went according to the rules, starting with 20,000 cu. ft. per min. and adding 1000 cu. ft. per min. every 24 hours. It just wouldn't work at all. Mr. Barrett decided that the only thing to do was to put the wind up, and of course that straightened the thing out, and now you start out with 20,000 or 25,000 cu. ft. per min. and add 1000 cu. ft. per min. every hour until you get up to 45,000 or 50,000.

Another instance that impressed me was on No. 3 furnace at Youngstown. At the blow-in they had tuyeres 15″ x 6″, as I recall. It was 23′–6″ diameter at the bottom, 19′–6″ on the top, with a bell 14 feet and some inches. It blew in according to the past practice, with the wind coming up fast. The iron ran .20 to .30 per cent sulphur. I thought to myself, "I wonder what he will do with her now".

When it came time to cast, he said, "Let's take down the tuyere". The tuyere was taken down, and believe it or not, there was raw ore. If I hadn't seen it myself I wouldn't believe it.

The tuyeres were 15″ x 6″. Mr. Barrett got some 12″ x 7″, and that furnace cleared right up and started making good iron, and to the best of my knowledge and belief 12″ x 7″ tuyeres were used during the rest of the blast.

WM. S. UNGER: As I see the modern blast furnace, the top will be supported by four columns running upward from the mantle and welded to the shell itself. In addition to supporting the top, this construction will give strength and rigidity to the shell. The top, of course, will be equipped with a distributor, an automatic stockline recorder, double skips of at least 250 cubic feet each, one downcomer emptying into the dustcatcher which will be considerably larger than those at present. The larry car will have two or possibly three compartments, the bells and hoist will be electrically interlocked, and the bells dumped at a constant speed. The hoist will have a speed of 600 feet per minute and operated by multi-voltage control.

The stoves will probably be 110 feet high and 25 feet in diameter and three in number; each stove being able to carry a straight line temperature of 1600 degrees F. They will have about 180,000 square feet of heating surface each giving a total of 500 to 600 square feet per ton of iron capacity. The openings will be graduated in several stages from top to bottom to give a constant velocity of gas. The exit gas temperature should not run much over 100 degrees F. higher than the inlet air. Toward the bottom of the stove, metallic checker construction will be used to get the last possible heat out of the gas.

The furnace will be blown by turbo-blowers operating on steam of about 700 pounds pressure and 750 degrees F. temperature, discharging into a surface condenser which should give a vacuum of not over one inch of mercury above barometric conditions. The boilers will be operated with preheated air, water cooled walls and auxiliary pulverized coal firing.

The iron ladles will have a capacity of 150-tons and be equipped with double trucks at each end. Shortly the wasting of dump slag will be eliminated and replaced by either granulation or dumping into pockets where it will be partially puffed up for use as concrete aggregate.

The future furnace will operate on a burden of 40 per cent sinter—this sinter being made up of a mixture of the fines of the ore, flue dust and what roll scale is available. The net coke rate will be 1600 pounds per ton and will be sized.

LUBRICANTS *for* MODERN CONTINUOUS *Rolling* MILLS

By L. BALLARD
Supervising Industrial Engineer
Tide Water Associated Oil Co.
NEW YORK, N. Y.

Presented before the A. I. & S. E. Thirty-fourth Annual Convention, Cleveland, Ohio, September 27, 28, 29, 30, 1938

▲ IT has been said that no one development has contributed more in the field of automotive lubrication than the application of the hypoid gear for modern cars. As a corollary it may be safely said that no one industry has contributed as much to the knowledge of industrial lubrication as the steel industry, and in no other industry are there as many varied and severe lubrication problems. Not only are most of the machines massive and subjected to heavy pressures, but many must be capable of precision adjustments which in turn means that bearing clearances must be small and more than the slightest amount of wear cannot be tolerated. The problem is further complicated by the difficulties in preventing contamination of the lubricants with water and abrasive scale, which are the natural enemies of lubrication.

Lubricant manufacturers cannot claim all of the credit for the advances that have been made in developing lubricants for the modern rolling mill as without the cooperation and the pioneering work on the part of the exceptionally well trained steel mill lubrication engineers, much of the progress that has been made would not have been possible. Credit should also be given to machinery and bearing manufacturers as well as to suppliers of lubricating systems and oil purification equipment for their share in what has been accomplished. Although lubricants and methods of applica-

FIGURE 1—The wide strip mill has presented a great many interesting lubrication problems.

tion have been developed which permit modern equipment to operate on an economical basis, efforts are continually being made to achieve still better results.

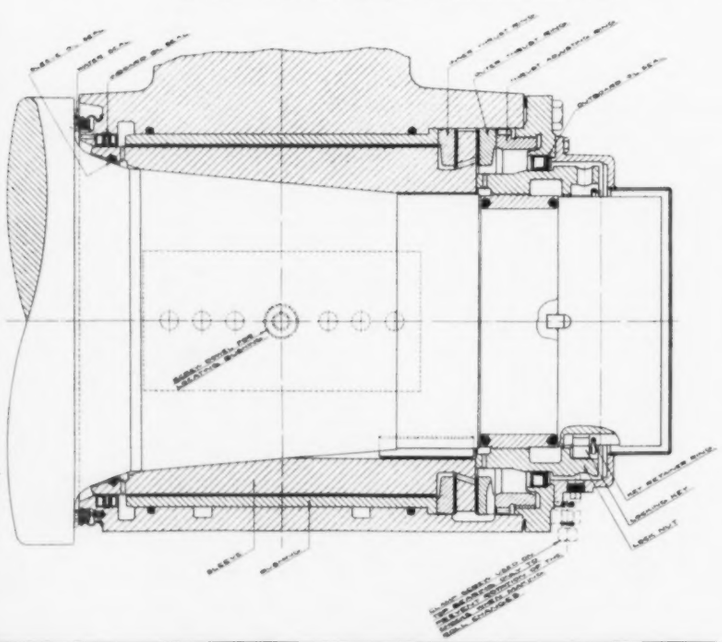
The extensive use of high speed continuous strip mills for rolling wide strips in light gauges has presented a number of lubrication problems of considerable interest and the object of this paper will be to discuss some of these problems.

OIL FILM ROLL NECK BEARINGS

The development of the oil film bearing for roll neck service represents a remarkable achievement in bearing design. In operation these bearings are completely separated from their journals by an oil film which is hydro-dynamic in action, and one of the essential requirements for satisfactory operation is that a flood of oil of the correct viscosity for the speed and load conditions be applied so that the clearance space between the journal and the bearing is always full of oil. This in turn necessitates a circulating oiling system equipped with suitable facilities for cooling and purifying the oil. A copious flow of oil is also important from the standpoint of cooling as practically all of the frictional heat generated must be conducted away by the lubricant and dissipated through the oil cooling facilities.

The conditions under which steel mill roll neck bearings operate make it difficult to entirely prevent undesirable impurities, such as water and mill scale, from entering the oiling system, but considerable progress has been made in developing and improving suitable bearing seals with the result that there is a remarkable freedom from contamination of the oil in most instances, particularly in the newer installations. On some mills contamination of the oil is still a problem, but these should be considered as exceptions rather than as representing general conditions.

FIGURE 2—Cross-section of oil-film bearing for roll neck service. (Courtesy Morgan Construction Company.)



Regardless of the efficiency of the bearing closures, there is a possibility that, because of damage to seals, excess water may get into the lubricant and for this reason the oil used should be capable of separating as quickly as possible from water. To meet this condition oil refiners have cooperated with the bearing manufacturers in making available oils possessing a high degree of demulsibility and excellent resistance to oxidation. For the lower viscosity oils used for oil film bearings on light duty mills there are no real difficult problems involved in the separation of impurities when good quality oils are used, but for the heavy duty mills where the oils used have Saybolt Universal viscosities ranging from 2,000 to 2,500 seconds at 100 degrees F. the problem is more severe and oils possessing the ability to separate from water far more quickly than conventional oils of the same viscosity are necessary for best results. However, the availability of oils for this service possessing exceptionally good demulsibility characteristics does not decrease the necessity of proper maintenance of bearing seals and full use of the installed facilities for oil purification, as scale and other abrasives are equally as abrasive in high as in poor quality oils.

Oxidation of oils tends to cause an increase in viscosity and this thickening effect is dependent upon the characteristics of the oil used, the operating temperature, the degree to which contamination occurs and the efficiency of the purification facilities. This increase in viscosity as a result of oil oxidation is objectionable as it results in an increase in frictional losses and makes separation of impurities more difficult. Therefore, it is important that the oils used for these bearings have exceptionally good resistance to oxidation in addition to good demulsibility if the desirable initial properties of the new oil are to be maintained for any long period of service.

Excessive contamination of the oil with water and other impurities does not occur in most instances, but there are some mills where the operating conditions are such that this is an important factor. Although these mills may be considered as exceptions, the problems involved are worthy of some comment. Little difficulty with oil purification would be experienced in such instances if water was the only impurity present as temporary emulsions of oil and pure water are not difficult to break up. However, when such emulsions are stabilized by solid impurities and any oxidized oil present they form permanent emulsions present as sludges which cannot be easily broken up and which must usually be removed as a whole from the oil. The following three analyses of samples of deposits from the oiling systems of oil film bearings on several continuous hot strip mills show the general composition of this kind of sludge.

	No. 1	No. 2	No. 3
Per cent unoxidized oil	23.2	8.0	13.2
Per cent oxidized oil	4.2	0.2	0.1
Per cent carbonaceous matter	6.8	6.3	0.1
Per cent water	36.8	76.2	52.6
Per cent ash (metallic oxides and silica)	29.0	9.3	34.0

Although these analyses differ somewhat in proportions of their various constituents, they are all characterized by the presence of relatively high percentages of water and scale (ash) and low percentages of oxidized oil. This shows that the oil in service does not have to be oxidized to any great extent in order to form sludges as long as solid impurities are present to stabilize any oil and water emulsions formed. These analyses also indicate the importance of maintaining the efficiency of the bearing seals and making full use of the installed facilities for oil purification.

In recommending a suitable viscosity oil for a specific installation, the bearing manufacturers do not have to resort to guess work as accurate formulas based on the hydro-dynamic theory of lubrication and supported by empirical data are available for selecting a suitable oil viscosity which will be known to provide fluid film lubrication for bearings operating under specified conditions of speed, pressure and oil temperature. In the case of continuous mills with several stands all supplied with oil from a common system, the oil viscosity is selected on the basis of the slowest speed bearing in order to provide the necessary factor of safety.

Developments in so-called "extreme pressure" lubricants for other types of service have resulted in some consideration being given to the use of such products for oil film roll neck bearings. Unfortunately the terms "film strength", "oiliness", "extreme pressure", "load capacity", etc. are loosely used and there are yet no clear cut definitions accurately differentiating between the various specialty products used in reducing friction and wear of very heavily loaded bearings or gear teeth. In general the term "extreme pressure" applies to those products used where the prevention of actual seizure of the opposing frictional surfaces is of more importance than the reduction of friction, and "oiliness" to those lubricants which give lower coefficients of friction than straight mineral oils of the same viscosity. However, regardless of the actual effect of such lubricants in reducing friction, wear or seizure, the fundamental theory of lubrication of oil film bearings should not be neglected in any study or consideration of their possible use on oil film roll neck bearings. It should be understood that these bearings are designed so that with an oil of the correct viscosity in service the journal, in operation, is completely separated from the bearing by an oil film which is hydro-dynamic in action and independent of the actual film strength of the oil used. As long as full film lubrication is in effect, any differences in film strength or oiliness of the lubricant will not affect frictional losses, as it is only when film lubrication fails and boundary lubrication becomes effective that extreme pressure properties serve a useful purpose.

As long as fluid film lubrication prevails the coefficient of friction is approximately proportional to the absolute viscosity of the oil and to the journal speed and inversely proportional to the unit bearing pressure. A typical curve showing the effect of oil viscosity, journal speed and bearing pressure on the coefficient of friction is illustrated by the solid line in the curves in Figure 2 in which the modulus $\frac{ZN}{P}$ is plotted against the coefficient of friction. This is the conventional method of showing

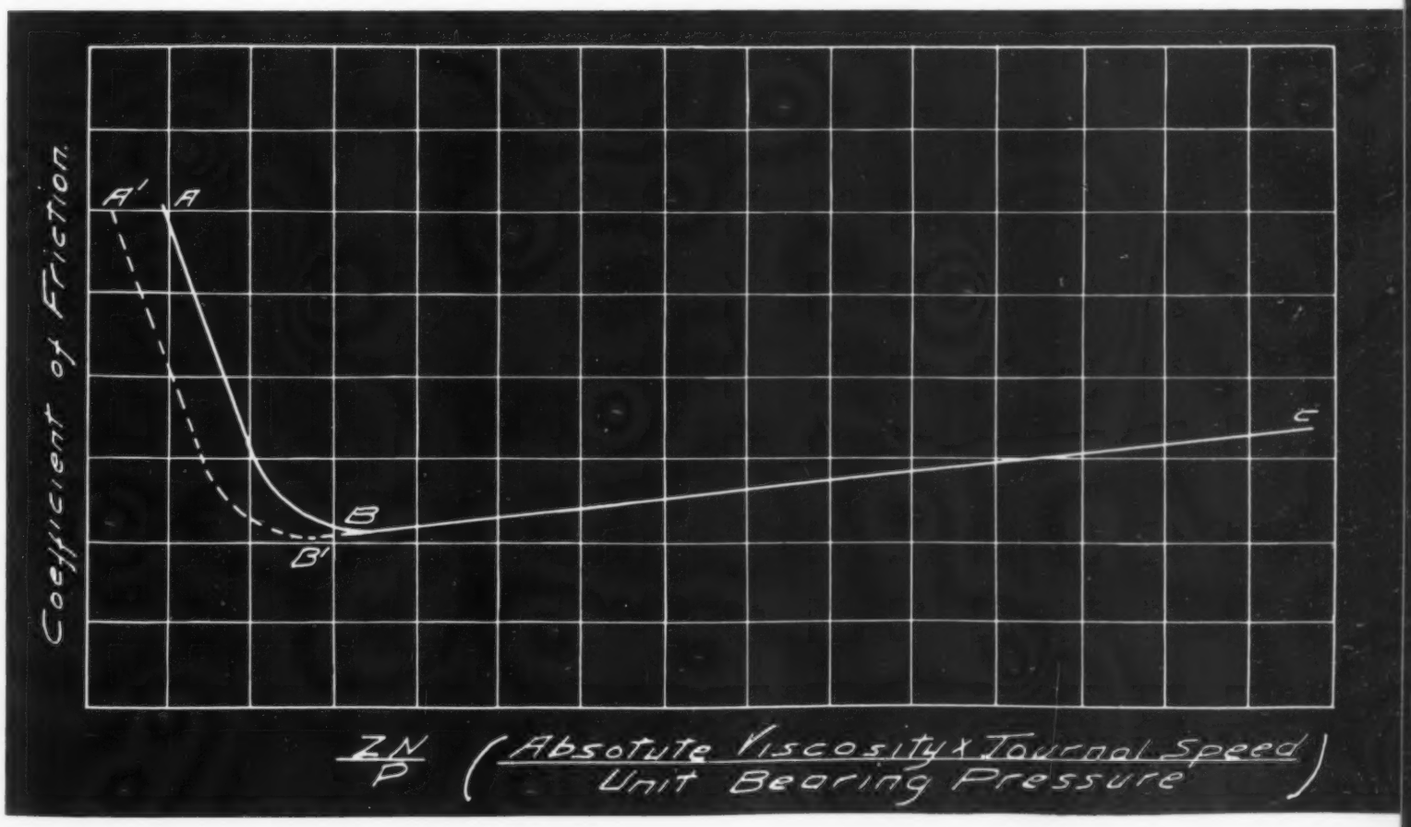


FIGURE 3—Curve showing typical effect of oil viscosity journal speed and bearing pressure on coefficient of friction.

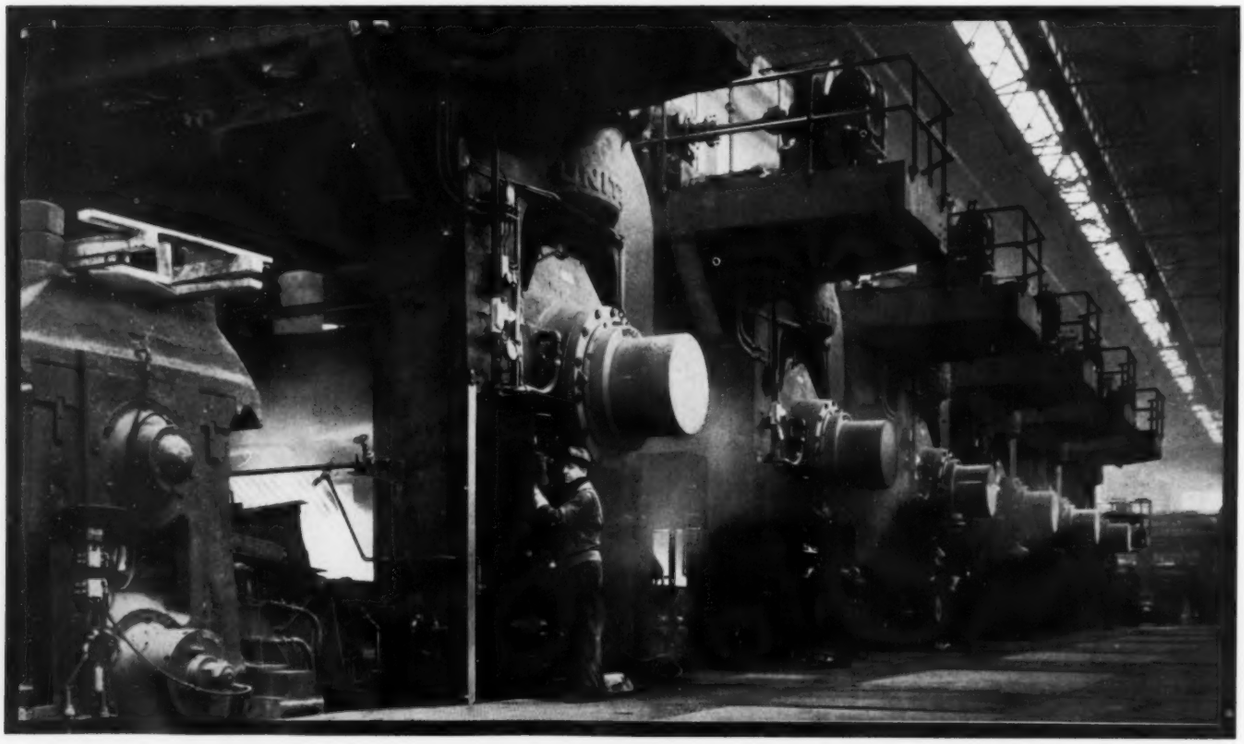
the operating characteristics of an oil film bearing, and Z represents the absolute viscosity of the oil at the operating temperature, N the speed of the journal and P the unit bearing pressure. Section AB represents the period immediately following the beginning of rotation of the journal when the oil film is being built up and as the journal speed increases the coefficient of friction decreases while the film is being formed.

At point B the oil film is fully formed and section BC represents the region of fluid film operation. As previously stated, the film strength of the lubricant used has no effect in reducing friction and wear as long as a fluid film separates the two opposing surfaces, such as in the region represented by the line BC. However, the load carrying capacity of the lubricant does affect the critical point B representing the transition point from boundary to fluid film lubrication, and any increase in film strength will increase the amount of load that may be carried at this point without film rupture, or will permit fluid film lubrication at a lower speed or with a lower viscosity oil in the critical region. If the curve ABC represents a straight mineral oil, the curve A^1B^1C is typical of an extreme pressure lubricant. It will be noted that the critical point on the curve has been moved to the left, but in the region of fluid film lubrication there has been no change in the coefficient of friction. It is, therefore, evident that as long as oil film bearings operate within the speed and pressure ranges for which they were designed and use the oil viscosity selected for the operating conditions there are no advantages to be gained through increasing the film strength of the lubricant.

ANTI-FRICTION ROLL NECK BEARINGS

Extreme pressure lubricants have found one of their widest applications in steel mills in the lubrication of anti-friction roll neck bearings, and much of the development work on extreme pressure greases for industrial use has been done in connection with this type of bearing. Theoretically there is only rolling contact between the rollers and their races, but there is sliding motion between the rollers and their cages or retainers and, in some types of bearings, between the ends of the rollers and shoulders on the rolling path of races, and for these points of sliding friction the ability of the lubricant to prevent wear and excess frictional heat is important. Also, the inner races of roll neck bearings are not generally a tight fit or keyed to the neck, and during operation slippage or creeping of the race on the neck occurs with the result that there is friction between the ends of the races and their opposing thrust surfaces. This involves the lubrication of annular flat surfaces of limited area, and for bearings subjected to heavy end thrusts the unit pressures at these points are very high and extreme pressure lubricants are necessary if maximum protection against wear and high frictional heat is to be obtained. The extent to which work roll bearings are subjected to heavy thrust loads is governed to a large extent by the rolling practice in any specific mill, and in some instances straight greases made with relatively high viscosity oils are reported to give good results. However, it is probable that even better results would be obtained if extreme pressure greases were used.

FIGURE 4—Improved lubricants and modern automatic equipment have answered the question of correct lubrication for continuous strip mills.



CONTAMINATION OF ANTI-FRICTION BEARING LUBRICANTS

In common with most other types of steel mill equipment, contamination of the lubricant used in anti-friction roll neck bearings with water and scale is one of the problems that must be considered. Scale is ever present, enormous quantities of water are used for cooling and steam descaling jets blow steam and scale almost directly at bearings, with the result that it is difficult to prevent contamination of the lubricant. Bearing seals are being improved continually but the conditions under which these bearings operate make it difficult in many cases to entirely prevent the entrance of impurities into the bearing housings. The following moisture and ash tests on samples of used grease from anti-friction bearings of several continuous hot strip mills indicate the extent to which this contamination may occur on a mill of this type.

Sample No.	Per Cent Water	Per Cent Ash (Iron, Iron Oxide and Silica)
1	49.0	0.30
2	22.4	2.74
3	36.0	5.80
4	24.0	1.00

Most of the greases used for anti-friction roll neck bearings are of the calcium soap type, and because this kind of soap is practically insoluble in water there is some misunderstanding regarding its ability to hold water in suspension. When water and a calcium grease are subjected to the milling action of an anti-friction bearing, the two become thoroughly mixed and the grease will actually hold an appreciable quantity of water in emulsified form. However, this is purely a mechanical mixture in contrast with the dissolving action of water on a sodium soap grease. The extent to which emulsified water will be visually evident depends upon the kind of mineral oil used in the grease, as a grease made with a highly filtered oil will turn to a creamy color when emulsified with water, whereas a grease made with a black oil will not change in color. Most greases used for this service are black and may hold considerable moisture in suspension without any change in color, and the fact that a black grease will mask the presence of water sometimes leads to the erroneous assumption that there is no moisture in the housing. However, the water emulsified with the grease does little harm as it is the free water that is not absorbed by the lubricant that may cause water etching or corrosion when a bearing is idle or out of the mill.

In so far as the effect on friction and overheating is concerned, the presence of water in the grease appears to have little effect on film strength as long as the quantity present is not in excess of that which the grease will hold in emulsified form. This has been substantiated by laboratory tests in which two entirely different types of extreme pressure greases were emulsified with water and the film strength of the emulsions determined. The water was thoroughly mixed with the two greases and the excess water squeezed out leaving for one grease 29 per cent and for the other 18 per cent of water as emulsions. Comparative runs were made on a lubricant tester with both greases, emulsified and straight, and no appreciable difference in load carrying capacity could be detected for either grease with and without water in emulsion. Also wear tests on the lubricant tester showed no appreciable difference between the respective straight and emulsified greases.

Pitting of rollers and races is often wrongly attributed to the lubricant in use, but actually the properties of the lubricant have little or nothing to do with this phenomenon. Faulty lubrication may cause destruction of rolling surfaces, but failure from this source is entirely different from the pitting and spalling resulting from fatigue of the metal and overloading or excess shock loads. When races become pitted they may be rotated in their housings so that a fresh surface is moved to the pressure zone, but rather than wait for fatigue of the metal to occur it is desirable to rotate races a few degrees whenever the bearings are open for cleaning and thereby relieve fatigue areas.

One of the cardinal rules for lubrication of anti-friction bearings in general is not to fill the housings too full of lubricant. However, when such bearings are operated in the presence of water and the lubricant subjected to contamination with both water and abrasive materials, such as is true of roll neck bearings in steel mills, it is often necessary to apply more lubricant than would be desirable under more ideal operating conditions. There is no uniformity in the amount of water used on various mills and the purity of the water also varies to a considerable extent with different mills. Consequently the possibility of water entering the bearing housings varies with each individual mill and the efficiency of the seals. However, decreasing the grease level too much results in more water getting into the bearings and for those mills with bad water conditions it is usually advantageous to keep the housings fairly well filled with grease. Any excess frictional heat generated by the additional grease is more than offset by the greater protection against entrance of water and abrasives.

CHARACTERISTICS OF ROLL NECK ANTI-FRICTION BEARING GREASES

Manufacturers of anti-friction bearings for roll neck service have done much valuable pioneer work in determining the characteristics desirable in lubricants for this service, and grease makers are indebted for the cordial cooperation that has always been extended by these manufacturers to anyone interested in benefiting by their experiences. Lubricant specifications issued by some manufacturers have been of considerable help to refiners in developing suitable lubricants, but many necessary and desirable properties cannot be well expressed in a lubricant specification and refiners must do more than merely make a grease to meet a given specification if optimum results are to be expected in actual service.

Considerable care must be taken in selecting extreme pressure bases for greases of high load carrying capacity as some types of addition agents for this service, if

present in excess quantities or not correctly incorporated, may exert a definite lapping action tending to promote bearing wear. It is possible for two lubricants to both give satisfactory load tests without scoring, but for one to have appreciably greater lapping action than the other. Therefore, in addition to film strength tests, extreme pressure lubricant should also be tested to determine if this lapping action is prevalent. Such wear tests supplement the load carrying tests and the two together give more information than either one alone.

Lubricants should also be tested to determine whether they are stable and if there is a possibility of corrosive action on the commonly used metals at the operating temperature to be expected in actual service. Since considerable water contamination is to be expected in some instances, all tests for load capacity, lapping action, stability and non-corrosive properties should be made on the grease both straight and emulsified with water to determine whether any desirable properties are adversely affected by moisture contamination.

The effect of low temperature on the consistency and pumpability of a roll neck grease is also of importance as the lubricant must be capable of being pumped through long lengths of piping in commercial high pressure greasing systems under any temperature condition prevalent in the mill. The following table shows the effect of temperature on a grease as determined in a variable pressure plasto-meter consisting of a Saybolt Viscosity tube fitted with a special tip and jacketed to provide for temperature control. The quantity of grease flowing from the tube in milligrams per second was determined at each temperature for a number of different pressures. The ASTM unworked penetration at three different temperatures is also given to show how the consistency of the grease on which these tests were made is affected by temperature.

GREASE FLUIDITY

Pressure Lbs./sq. in.	10	20	30	40
Temperature Degrees F.	Efflux—Milligrams per Second			
0	....	....	1.8	3.5
10	....	0.8	5.0	10.5
32	1.6	13.3	26.4	44.4
58	21.0	75.0	155.2	260.0

GREASE CONSISTENCY

A.S.T.M. unworked penetration at 0 degrees F.	225
A.S.T.M. unworked penetration at 10 degrees F.	267
A.S.T.M. unworked penetration at 77 degrees F.	285

The above fluidity determination apply only to the specific grease tested as the type of soap and the kind of mineral oil incorporated in the grease affect this characteristic, but the general effect of temperature on pumpability and consistency is illustrated.

LUBRICANTS FOR PINIONS AND REDUCTION GEARS

Pressure circulating oiling systems with the necessary oil cooling and purification facilities are standard for pinions and reduction gears of modern continuous mills, as well as for most other modern mill drives. Straight mineral oils having Saybolt Universal viscosities of from 2,000 to 2,500 seconds at 100 degrees F. are extensively used and are giving satisfactory results. Although the oils in such systems are not usually subject to contamination to the degree prevalent on roll neck bearings and, consequently, do not demand the very good demulsibility necessary for oil film roll neck bearings, nevertheless, a filtered oil which will readily separate from water is desirable for best results.

Straight mineral oils are being used in the majority of instances for mill drives and pinion stands lubricated by means of circulating systems, but considerable work has been done in the application of extreme pressure lubricants for splash lubricated gears. Developments in oiliness and extreme pressure agents for other types of service has resulted in consideration of these products for use in circulating systems, such as for gears and pinions, when lubricants possessing high load carrying capacity are necessary or desirable. An important factor involved in the consideration of extreme pressure lubricants for this service is the effect of the additives necessary to improve film strength or the demulsibility and resistance to oxidation of the oil. Extreme pressure lubricants are effective as such because they are more chemically active than straight mineral oils and, being so, may be more easily oxidized and less capable of rapid separation from water and other impurities. Therefore, any attempt to utilize such products for circulating systems, without due regard for this factor may be detrimental to lubrication.

It is also important that extreme pressure lubricants for gears, and any other service involving a circulating system, be stable so that there will be no separation of the ingredients when treated by any of the commonly used methods of oil purification. Centrifuges are commonly used for purifying circulating oils and the tremendous centrifugal force exerted by this type of clarifier tends to cause separation of an unstable product. Oils which must be specially handled and which cannot be treated or purified in the same manner as other circulating oils do not make the most desirable steel mill lubricants.

At the present time oiliness agents are available which do not adversely affect the demulsibility of an oil to which they are added, but such products are relatively mild in their effect on film strength in comparison with the more active extreme pressure agents. However, such products are worthy of investigation in the general consideration of circulating oils, and the results of adding one of them to a straight mineral oil having good demulsibility and a Saybolt Universal viscosity of 154 seconds at 210 degrees F. are indicated

in the following table giving load tests on both the straight mineral and compounded oils on several different test machines.

Test Machine	Load Valves	
	Mineral Oil	Compounded Oil
Almen Machine	8 lb.	18 lb.
Timken Machine Rubbing speed 400 ft./min.	22 lb.	27 lb.
S.A.E. Machine Roll ratio 14.6:1, Loading rate 83.5 lb./sec., Speed 890 rpm	63 lb.	76 lb.

	Wear Tests	
	Mineral Oil	Compounded Oil
Timken Machine 400 ft./min. rubbing speed, 22 lb. lever load Loss in grams	0.0015	0.0012

The additive used in making the above tests did not adversely affect demulsibility, and it will be noted that wear tests on the Timken lubricant tester at a constant load showed a decrease in wear in favor of the compounded oil. It will also be noted that the degree of improvement in load carrying capacity depends largely upon the test machine employed and the purpose for which it was developed. The Almen machine showed an increase in the load carrying capacity of 125 per cent, while the Timken and S.A.E. machines gave increases in loads of only 23 per cent and 20 per cent respectively. This is not unexpected as film strength or oiliness is not a sole function of the lubricant, but is a joint property of the lubricant and the metals composing the frictional surfaces and is influenced by rubbing speed and the condition of the opposing metal surfaces. These tests on different machines also demonstrate why it is impossible to make a general statement giving load carrying capacity of any lubricant in terms of a specific number of pounds per square inch pressure, as the results on different machines when converted to pounds per square inch pressure vary to a considerable extent and even on any one machine the load carrying capacity of the same lubricant would be different with steel against steel from steel against bronze.

EFFECT OF METALS ON CIRCULATING OILS

The effect of the metals commonly used in oil circulating and purification systems on deterioration of the oil is an important subject which only in recent years has been given the consideration that it deserves. It has been found that certain metals act as catalysts and tend to increase the acidity, and consequently the rate of deterioration, of oils with which they come in contact at a more rapid rate than other metals. Zinc, lead and alloys of copper have all been found to have an effect on the rate of increase in acidity of circulating oils, whereas iron, steel and aluminum have little effect of this nature. However, this deteriorating effect is greatly intensified when the metals are in finely pulverized form and mill scale and blast furnace dust should be kept out of oils as far as possible for this reason as well as because of their abrasive properties.

As iron and steel are not active in their effect on oils, these metals are the most desirable to use in constructing oil circulating and purification systems for oil film roll neck bearings, gears and any other equipment lubricated by this method. Galvanized material should be avoided as far as possible in the construction of oil filters because of the catalytic effect of the zinc coating on oil, and copper and brass piping are undesirable because of their effect on oils. Alloys of copper are used to a considerable extent for tubing in oil coolers and depending upon the surface exposed to the oil seem to exert a definite deteriorating action. However, the cold tubes of the cooler tend to precipitate from the used oil some of the products of oil oxidation soluble at the higher operating temperature, and this material usually coats most of the surface of the tubes with a thin film which tends to prevent any further direct contact of the oil and the metal surface so coated.

Most of the work done on the effect of metals on oils has been in connection with steam turbines and in turbines that are unusually severe on the lubricant it is not uncommon to find heavy traces of metallic soaps present in the oil which could only come from reaction of the oil with the metals with which it comes in contact in the oiling system or from contamination of the oil with dusts containing metals and metallic compounds. The following analyses of the ash contents of sludges from two turbines in different plants are examples of the extent to which metallic compounds may be present.

	Sample No. 1	Sample No. 2
Per cent zinc oxide	9.30	1.04
Per cent copper oxide	5.00	5.50
Per cent iron oxide	72.40	85.00
Per cent tin oxide	3.10	....
Per cent magnesium oxide	....	0.06
Per cent silica	10.10	8.00
Per cent unidentified	0.10	0.40

Sample No. 1 is from a turbine in a power plant in which galvanized metal was used at the time in the oil filter. This turbine had always been severe on the oil and an appreciable change in acidity followed the breakage of a bronze worm gear governor drive which permitted this metal in finely ground form to enter the oil. Sample No. 2 is from a steel mill turbo-blower

operating in the vicinity of blast furnaces and although other adverse operating conditions made it difficult to determine whether the catalytic effect of metal was primarily responsible for the severity of this unit on this oil, in the light of other experiences it is probable that this was one of the contributing factors.

What has been learned about the effect of various metals on steam turbine oils is equally applicable to circulating oils used for sleeve type roll neck bearings, gears and other equipment, and although much still remains to be learned about this subject, it is an item that should be given consideration in the design and construction of any oil circulating and purification equipment.

DISCUSSION

PRESENTED BY

O. L. MAAG, Lubricating Engineer, Timken Roller Bearing Company, Canton, Ohio.

H. H. WOOD, District Manager, Morgan Construction Company, Pittsburgh, Pennsylvania.

H. A. SMITH, Socony-Vacuum Oil Company, Inc., Pittsburgh, Pennsylvania.

N. M. AYCOCK, Lubrication Engineer, Texas Company, New York, New York.

H. R. GILCHRIST, Lubricating Engineer, Carnegie-Illinois Steel Corporation, Youngstown, Ohio.

F. J. THOMAS, Lubrication Engineer, Republic Steel Corporation, Cleveland, Ohio.

R. C. WALTER, Penola, Inc., Chicago, Illinois.

L. BALLARD, Supervising Industrial Engineer, Tide Water Associated Oil Company, New York, New York.

O. L. MAAG: Mr. Ballard has correctly pointed out that much of our lubrication troubles in steel mill lubrication can be traced to contamination by water, mill scale and dirt. The analyses presented are similar in all mills; therefore, designing engineers have a common problem and should find more effective ways of keeping out the foreign matter. Better shields and bearing seals are necessary and undoubtedly will be forthcoming soon. Filters and centrifuges are valuable in removing these substances from contaminated oil, and thus clean lubricant is returned to the system. However, it is very desirable to prevent their entrance as much as possible into the lubricant, as this would eliminate the corrosion and wear brought about by these substances. Etching of bearings by water has started many on the road to early failure or unsatisfactory service.

Centrifuges and filters give best results when well refined and fairly light bodied oils are used. As these oils become oxidized quite stable emulsions will be formed with water and dirt, which reduces the efficiency of these methods of oil purification. The steel industry is in need of better compounded oils that can be used in systems where the above methods of purification are used.

With grease lubricated anti-friction roll neck bearings, the grease is used both as a lubricant and as an aid to the bearing seal to keep water and dirt out of the housings. The increased amount of water together with the milling action of the bearings thins out the grease and when new lubricant is periodically forced into the housing the contaminated portion being the softer will be forced out by the closures, thus insuring clean, moisture-free lubricant about the bearing which prevents etching and corrosion.

Some steel mill greases on the market today do not thin out as much as others with the same percentage of water, which indicates that some grease makers have not as yet produced the best product they are capable of making.

Laboratory engineers should watch this point as well as seeing to it that the product they buy does not have too great a difference between worked and unworked consistencies.

H. H. WOOD: Mr. Ballard's paper on "Lubrication for Modern Continuous Rolling Mills" covers in concise form many subjects of interest to all of us who have to do with the lubrication of rolling mill machinery. My discussion will be limited to that part of the paper dealing with lubrication of oil film roll neck bearings.

We are convinced that a straight mineral oil of high quality and high demulsibility with excellent resistance to oxidation is the most satisfactory lubricant for this type of bearing. Mr. Ballard has stressed these points in his paper but he has not mentioned viscosity index, which we believe important, particularly in the heavier grades of lubricating oil. An oil with a high viscosity index does not thin out as rapidly under increased temperature and, therefore, aids in safeguarding the minimum $\frac{ZN}{P}$ which is necessary for fluid film lubrication of this type of bearing.

With reference to increase in frictional losses in these bearings when an increase in viscosity occurs due to oxidation of the oil, we would say on the average that coefficient of friction might increase three or four percent for a viscosity increase of as much as ten percent. Assuming that coefficient of friction for a particular combination of viscosity, speed and unit loading is .002, a four percent increase would bring the coefficient up to .00208. The power dissipated in friction would be increased four percent, but, in a typical case, the total horsepower used in friction is only four percent of the horsepower applied to the roll necks. Therefore, total power applied to the mill would only be increased .16 percent which is negligible. Looking at it another way, the oil could be brought back to its original viscosity by carrying temperature at the suppply riser at the mill about three degrees higher.

With reference to protection of our bearings from water or other coolant used over the mills and from mill scale, considerable progress has been made in

design and application of seals to the point where little, if any difficulty is experienced in contamination of the lubricating oil. We receive through the courtesy of some of the large oil companies, periodic test reports on the condition of lubricating oil in large hot mill systems and the excellent oils used are standing up remarkably well. Centrifuging of the oil is done very infrequently and, in many cases, no centrifuging is necessary. Naturally, seals, which are wearing parts, must be maintained in good operating conditions.

Mr. Ballard has discussed a curve plotted with coefficient of friction as the ordinate and $\frac{ZN}{P}$ as the abscissa. Except in the case of a protracted shut down with mill under load, our type of bearing operates in the region of perfect film, which, on his curve, is marked B-C. The accuracy and finish of the rotating and stationary parts of the Morgoil bearing has brought point B, minimum $\frac{ZN}{P}$, where we get into boundary lubrication or film failure, much closer to zero than was previously the case before the development of this bearing. This means that it is possible to operate at extremely low rotating speed and still maintain separation of journal and bushing by means of a perfect film of oil. We have not found it necessary to consider any additives to the straight mineral oil, neither the type that would increase oiliness nor the type that would give extreme pressure properties, in order to carry heavy loads at low speeds. We do not believe that these additives are desirable or necessary as we feel that, in all probability, they will decrease demulsibility.

In addition, we are not at all sure that they will decrease the minimum $\frac{ZN}{P}$.

We recently witnessed a test on a straight mineral oil and an oil of similar viscosity having extreme pressure properties. The testing machine rotated a steel cup against a hardened steel roller whose axis was at 90 degrees to that of the rotating cup. In each case the load was gradually applied by the addition of weight to a lever arm. When the same number of weights had been added in each comparative test and previous to any scoring, the test rollers were removed and examined and each showed a considerable area of wear. These areas were apparently identical. Previously, similar comparative tests had been run to the scoring point and the oil with extreme pressure properties carried three times as many weights as straight mineral oil when scoring occurred The last mentioned comparative test was supposed to demonstrate superior film strength of the oil with the extreme pressure properties, but, to us, it apparently showed only that this oil had the property of permitting more wear without destructive scoring. For our type of bearing to be successful, wear must be absent or negligible, and what we are after is an oil of correct viscosity which will give a perfect film under the load and speed conditions existing and thereby prevent any wear.

H. A. SMITH: There were three things on which I would like to comment. The first is, where it was marked on his chart that the mineral oil carried twenty-two pounds on the Timken machine, that must have been a compounded oil or possibly so viscous that they did not easily get metal to metal contact. Straight mineral oils usually carry from twelve to fourteen pounds.

In the matter of piping—of course, as he said, the zinc is very bad. With the copper alloy type, you at least get rid of the rusting which you get with some other types of pipe. When rust drops into the oil and is carried back to reservoir, it is a fine catalyst to help ruin the oil.

The third point I have, is the comparative extreme pressure value of the grease when it contains different percentages of water. Some recent tests with extreme pressure greases of the lead-naphthenate type, indicated that you could add considerable water to such a grease without losing a great deal of the extreme pressure value. He didn't mention whether he was speaking of that type of grease or of the lime sulphur type of grease. That may make a difference.

N. M. AYCOCK: Mr. Ballard discussed the heavy oils used for oil film roll neck bearings, and emphasizes the necessity of full demulsibility of these oils. I believe that one comment can be made here; that is, the necessity for these oils to maintain their stability in service and continue to separate readily from water over long service periods. Some oils may have a high demulsibility when new, then lose this important characteristic when they are compelled to encounter water and various kinds of foreign matter.

One point brought out by Mr. Ballard that I am sure relieves the worry of many a steel mill engineer, is where he speaks of extreme pressure greases used for lubrication of anti-friction bearings. He advises that tests have proved that a high percentage of water does not seem to impair the load carrying capacity of the lubricant.

Mr. Ballard has indicated that in steel mill operations, where a great deal of water is used, it is often necessary to carry more lubricant in an anti-friction roll neck bearing so that there is not sufficient space present to entrain a lot of water. There is one point which I wish to emphasize with regard to this subject; that is, in many reports of anti-friction bearings heating up, when the operation is dry, it was found that, most of the time, an overfilling of the bearings caused the heat condition.

In Mr. Ballard's paper, he told us that extreme pressure oils were more chemically active than straight mineral oils. Therefore, these might more easily oxidize and not separate rapidly from water and other matter. I believe this is entirely governed by the type of extreme pressure additive, the kind of mineral oil and the method of manufacture, as there are extreme pressure oils which do resist emulsification over long service periods.

H. R. GILCHRIST: I was very much interested in Mr. Ballard's paper, and I do believe there is a place for extreme pressure lubricants as well as for straight mineral oil. I believe we have to go along

with these different oil companies and use their oils and greases in the right places.

It is my opinion that more trouble is caused by improper seals and the improper distribution of the lubricants. I have visited a good many plants that were having so-called oil troubles and have found that the distribution of oil was faulty. In one of the plants I visited, one of the pinions was badly spalled, and the rest of the pinions, in the same circulation system were in good condition. I was told that the oil was not standing up. But after checking with the man in charge, found that the bad pinion was torch hardened, and the rest were heat treated before machining. I believe it would be better if we made a thorough study of our conditions before making complaints about the lubricants.

F. J. THOMAS: Mr. Ballard has given us some very good service data on oils and greases in use in our present day mills.

Referring to Mr. Ballard's remarks concerning lubricants for pinions and reduction gears, I do not feel that a filtered oil which will readily separate from water is necessarily desirable for these units. Properly designed and sealed, no free water will enter the gear cases or pinion housings and their respective oil circulation systems. Furthermore most extreme pressure oils now in use, although not of the filtered type mentioned by Mr. Ballard, have proven thoroughly satisfactory for use in oil circulating systems serving gears and pinions. With water a negligible quantity, centrifuging is unnecessary. Even in oil film bearing systems of proper capacity where the bearings are properly sealed and the seals properly maintained, centrifuging should not be resorted to except under unusual circumstances. Experience has shown this to be desirable.

I would like to suggest that with pinions and reduction gears equipped with roller bearings, little, if any cooling equipment is needed for the oil circulating systems; and, by preventing the entrance of water, elaborate oil purification systems are unnecessary. This makes it desirable to use a suitable extreme pressure lubricant to give added protection to the bearings as well as to the gears. With roller bearings, we have steel against steel all the way through, and lubrication is simplified, gears and bearings may both be adequately served by the same lubricant and a good extreme pressure lubricant will be more satisfactory than a straight mineral oil.

R. C. WALTER: The modern continuous strip mills are precision tools and must be lubricated and maintained as such. Mr. Ballard has stated in his paper that the lubricant manufacturer has, with the cooperation of the mill designers, engineers and operating personnel, kept pace with this recent development in steel production and I believe that today lubricants are available to meet the load, speed and operating conditions of these mills.

Credit must also be given to the suppliers of circulating systems for fluid lubricants and centralized pressure systems for non-fluid lubricants for their developments, for no matter how perfect a lubricant may be it cannot function properly unless correctly applied and their many improvements have greatly aided in the proper application of these new lubricants so that full advantage of their quality can be secured.

With correct lubricants correctly applied, the principal remaining problem is to maintain them in proper condition. Mr. Ballard has fully covered the effects of contamination of oils and greases and the necessity of keeping them up to standard. Naturally the problem would be greatly simplified if contamination could be prevented at its source and while this may seem to be a problem for the mill equipment designer, with several problems still to be solved, much progress has been made and the burden of the work in preventing contamination is now more or less on the shoulders of the mechanical department of the mill. A high standard of cleanliness in the mill, frequent inspection of gears and bearings, and precision maintenance work will be definitely reflected in lowered maintenance and lubricating costs as well as in improved finished product.

These new lubricants will withstand an immense amount of abuse of every kind but they still cannot correct mechanical defects and maintenance work must be of the same high standard as the mill equipment. It is, of course, practically impossible to entirely prevent contamination but the more work along the line of prevention the more simple will be the problem of reconditioning and maintaining the original standard of the lubricants.

Much attention has been paid to the lubrication and maintenance of the modern continuous strip mill but there has been a tendency to let the older mills and equipment continue along the same old fashioned way. I have found that the use of the newly developed lubricants and their methods of application in the older type mills offer great possibilities for improved operation, lubrication and maintenance cost reduction. While in many cases such a change over may involve considerable expense, we invariably find that the savings effected will pay for these changes in a short period of time. I do not think that our interest in the newer type mills should lead us to neglect the possibility of improvements in the lubrication of the older type mills.

L. BALLARD: With reference to Mr. Wood's comments on the desirability of good viscosity index in oils for oil-film roll neck bearings, we agree that this is an important characteristic which should be given consideration. Referring to comments on the fact that all oils having extreme pressure or high oiliness properties do not necessarily reduce the amount of wear in comparison with a straight mineral oil of the same viscosity when subjected to a friction test, this is true, but there are products which will both increase the load capacity and reduce the wear. The compounded lubricant discussed in the section of the paper on "Lubricants for Pinions and Reduction Gears" has these characteristics as tests on three different types of test machines showed appreciable increases in load capacity and also a reduction in the amount of wear when subjected to the wear test on a Timken machine, in comparison with the same mineral oil not compounded.

With reference to Mr. Smith's comments on Timken load tests, the results reported for the straight mineral oil represent the load necessary to produce scoring and the final result is based on the average of a number of tests. The remarks in the paper covering the effect of moisture on extreme pressure greases were based on tests with sulphurized base, lead soap and lead soap-sulphurized base greases and all three types showed the same results in that as long as the moisture was present as an emulsion with the grease there was no noticeable reduction in load capacity or increase in wear.

We thoroughly agree with Mr. Aycock's remarks regarding the importance of stability in circulating oils as it is very important that the oil retain its initial properties as much as possible over a long period of time. It is not difficult to make oils with good initial physical properties, but it is possible to have two oils of the same demulsibility characteristics when new that will differ to an appreciable extent after an extended period of service. With reference to remarks regarding oxidation characteristics of high film strength lubricants, we believe that all such products that fall in the classification of active extreme pressure lubricants are more easily oxidized than good quality straight mineral oils. However, there are oiliness agents and methods of treatment which will improve load capacity without adversely affecting demulsibility or stability but we would not classify such products as active extreme pressure lubricants.

Mr. Gilchrist's remarks on the effect of other factors besides the properties of the oils or greases used on lubrication difficulties are of interest and are appreciated as we all know that the ease with which many

(*Please turn to page 56*)

ANNUAL *Spring* CONFERENCE

BIRMINGHAM, ALA. MARCH 27-28, 1939

MONDAY, MARCH 27th.

8:45 A. M.—Registration—Main Lobby, Hotel Tutwiler

9:00 A. M.—Technical Session, Ball Room

Chairman	Vice Chairman
R. R. THOMAS, Asst. Chief Engineer, Tennessee Coal, Iron & Railroad Company.	C. C. PECU, Lubrication Engineer, Bethlehem Steel Company

"Relay Protective Methods for Steel Mill Service"—H. A. TRAVERS, Power System Engineer, Westinghouse Electric & Mfg. Company.

"Modern Wire Drawing Practice"—J. J. PHIFER, Supt. Fairfield Wire Works, Tennessee Coal, Iron & Railroad Company.

"General Types of Lubricants Essential to the Steel Plant"—WM. MANDY, Texas Company.

12:30 P. M.—Luncheon. Address by A. B. HASWELL, Asst. to Vice President, T. C. I. & R. R. Co.

1:45 P. M.—Inspection trip to plant of American Cast Iron Pipe Company, Birmingham, Alabama. Busses from Hotel Tutwiler.

6:00 P. M.—Dinner. Address by ROBT. GREGG, Pres. Tennessee Coal, Iron & R. R. Co.

8:00 P. M.—Technical Session, Ball Room

Chairman	Vice Chairman
H. T. WATTS, Combustion Engineer, Republic Steel Corporation	J. A. CLAUSS, Chief Engineer, Great Lakes Steel Corp.

"Modern Pit Design and Practice at Fairfield Works"—E. A. HAWK, Fuel Engineer, and M. P. BURNS, Asst. Fuel Engineer, Tennessee Coal, Iron & Railroad Company.

"Unique Features in Southern Blast Furnace Practice"—GEO. RAMSEY, Research Dept., Tennessee Coal, Iron & Railroad Company.

TUESDAY, MARCH 28th.—(Entire Day)

8:30 A. M.—Inspection Trip to Tennessee Coal, Iron and Railroad Company properties.

HEADQUARTERS - HOTEL TUTWILER

LIGHTNING and SURGE Voltage Protection for A. C. ROTATING MACHINES

By P. J. WALTON
Application Engineering Div.
GENERAL ELECTRIC CO.
SCHENECTADY, N. Y.

Presented before the
A. I. & S. E.
Philadelphia District Section
February 5, 1939

▲ THE wording of the subject of this paper implies that the technique required for the protection of rotating machines is different from that which is satisfactory for transmission lines, transformers, oil circuit breakers and other forms of stationary equipment. We shall divide this subject into four parts; namely, why rotating machines present a separate problem, what this problem is, what can be done about it, and what has been done about it.

In order to understand why there is a separate problem, let us consider some differences between transformers, for example, and motors. In this paper we shall consider that motors and generators are the same, as regards the protection required.

Transformers have bushings which may flash over before damage has occurred to the windings inside the tank. The transformer windings are immersed in oil and the end turns may be made with extra heavy insulation. The allowable impulse test voltage for a transformer is about twice the crest of the 60 cycle test voltage.

Motors, on the other hand, do not have any advance guard to flash over before failure inside the windings will occur. The insulation is dry. There is no extra heavy insulation on the end turns, and the test impulse ratio in some instances may be as low as unity; that is, the insulation in a motor may not withstand any higher impulse voltage than it will 60 cycle crest voltage. The coils are in slots and have corners. Foreign material may get into the coils. The space for the coils is limited, and it is necessary to put copper in the coils as well as insulation, and the size of the coil may not be increased because it is also necessary to have iron. In other words, it is impracticable to make motors and generators with high dielectric strength, and in the interest of conservatism, it is preferable to regard the crest 60 cycle test voltage as the maximum impulse voltage. In other words, a transformer has a two to one advantage over a motor.

It is, therefore, more economical to protect than to insulate, and this type of equipment should have protection against lightning and surge voltages, and operators are beginning to realize the value and importance of this protection for motors and generators.

To understand this better, let us consider a machine winding under impulse voltage.

Figure 1 shows a cathode ray oscillogram of artificial lightning voltage, measured at the neutral of a motor, and produced by a traveling wave of 1000 volts coming in over a line of 400 ohms surge impedance and which will be explained later. Let us consider that this wave is actually entering the motor, and to make it more interesting multiply the voltage scale by ten. As the horizontal ordinate represents time in millionths of a second, and as such a wave travels at a definite speed through the machine windings, a certain time will then also represent the length of the first turn of the line terminal coil of the motor. We then have a certain voltage, as indicated by the oscillogram for that amount of time, at the beginning of the first turn, when there is zero voltage at the other end of the first turn, and, therefore, across the turn insulation, and this voltage may cause this insulation to fail. You will note that the steepness of the wave front determines the magnitude of voltage across this turn, and, therefore, on the turn insulation.

The writer saw one case of a 6600 volt, 1000 kw. turbo-generator with 92 volts per turn normal voltage, connected to overhead transmission lines on wooden poles, which could easily bring in 100,000 volts or more, of lightning. This machine failed in the first turn at the nose of the coil, and outside of the iron, so it did not fail to ground. The copper conductor was about ½ inch x ¼ inch and a semi-circular hole was burned on the side of this copper, showing where it had failed across the insulation between turns. This machine was insulated with mica and failed five times in eight months.

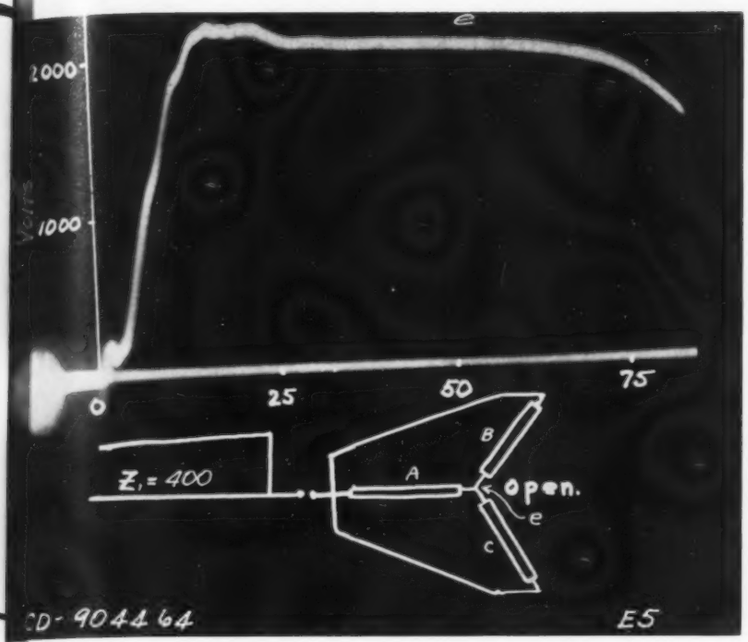


FIGURE 1—Cathode ray oscillogram of artificial lightning voltage produced by wave of 1000 volts.

FIGURE 2—Oscillogram of lightning voltage that has passed through transformers in the diagram shown at the top.

LIGHTNING THROUGH TRANSFORMERS

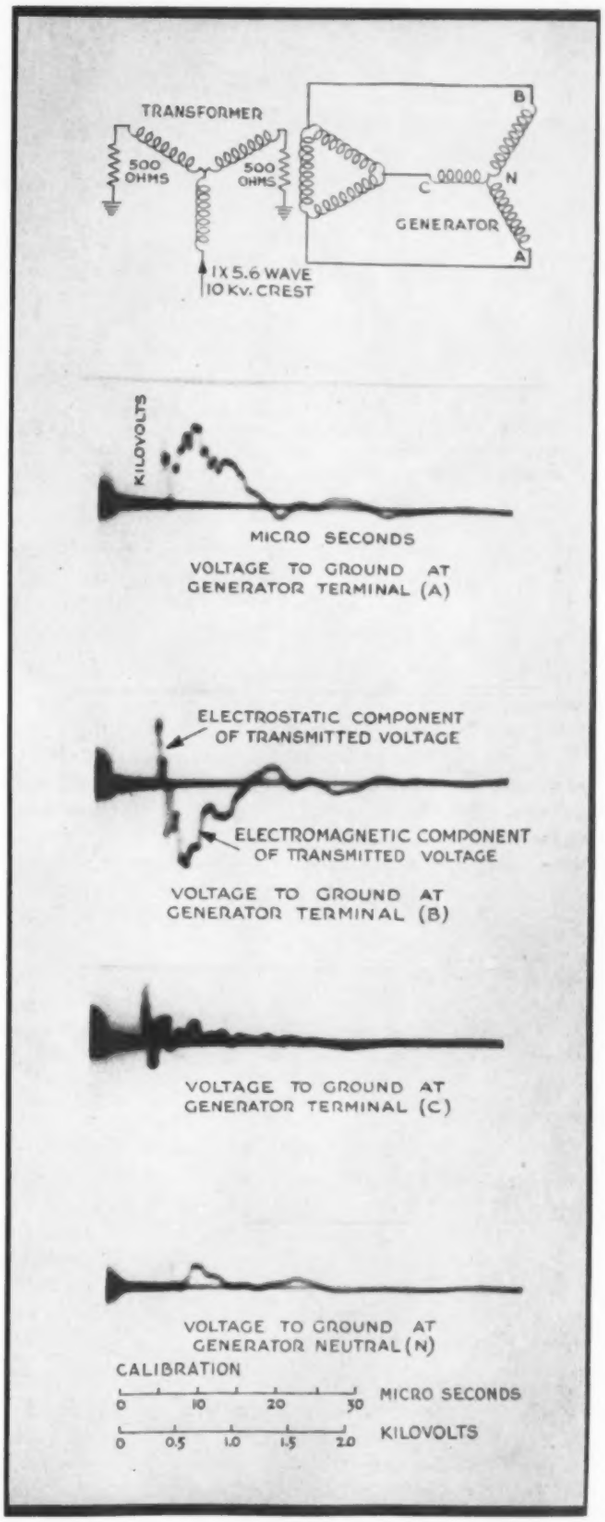
Transformers are not the barrier to lightning that they were once thought to be. Lightning voltages will pass through transformers in four different ways; two oscillatory, one electrostatic and one electromagnetic. This last is the most important. We must, therefore, protect motors and generators whether they are connected to overhead lines either directly or through transformers.

The oscillatory voltage is small and has little effect. The electrostatic voltage is very steep and mainly affects the turn and coil insulation of the line terminal coils. The electromagnetic component has the majority of the energy and may be dangerous to the machine insulation. Figure 2 shows lightning voltage that has passed through transformers. This voltage should, therefore, be reduced by an arrester on the line side of the transformer, which will also serve to protect the transformer.

In one case, lightning came in over a 110,000 volt transmission line, passed through transformers to 11,000 volts, then through another bank of transformers to 2300 volts, where it caused the failure of a 700 hp., 2300 volt motor.

In another case, when there was no lightning occurring, so there must have been an arcing ground or switching surge, or combination of them, surge voltages passed through transformers from 66,000 volts to 13,000 volts, then over a few miles of overhead line and cable to another bank of transformers, stepping down to 2300 volts, and causing the failure of a 2300 volt motor, which also happened to be 700 hp. In this case, the failure was through the coil insulation and across the air to the end shield.

In the three cases mentioned, the machines were built by three different large electrical manufacturers and were in three different localities.



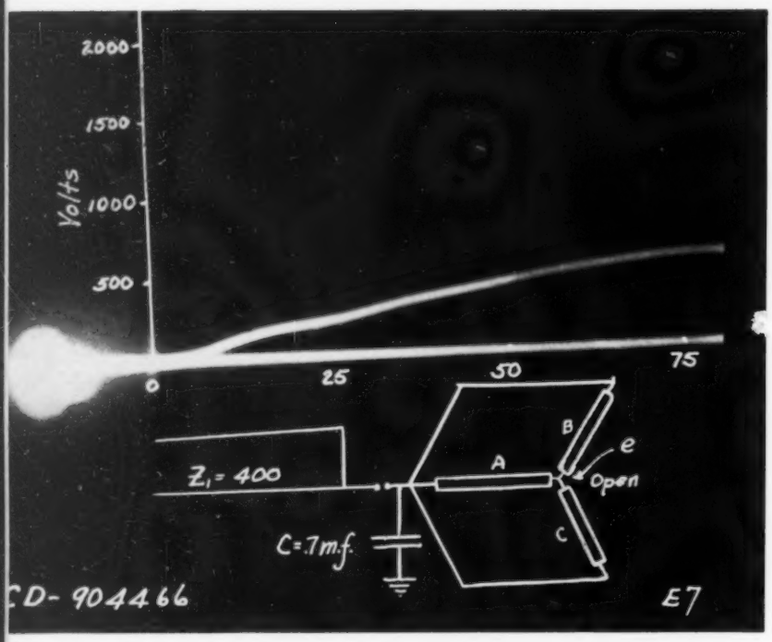


FIGURE 3—Oscillogram from same motor as in Figure 1, but with a capacitor between line terminal of the motor and ground.

SWITCHING SURGES

The coils of a motor may be considered as a capacity network with a condenser between the first and second turns, and between the second and third turns, and between all of them and ground. When a switch closes, one phase closing first, the voltage causes a charging current to flow between the first and second turns of the motor and to ground. The charging current across this capacitor produces a high turn voltage in the line terminal coils. The limit in magnitude of voltage is the crest of the line to neutral voltage, or in the case of a 2300 volt motor, 1880 volts. This is an instant change, in nothing flat—a very steep wave. Field tests show that when full voltage is applied to an unexcited motor, the transient in the end coil may be 70 per cent of the crest voltage applied. Compared with lightning it is of less magnitude and of shorter duration, only about one-half millionth of a second.

This sliver of voltage may cause failure of the turn insulation, but does not ionize a path and the power current does not follow, that is, it is a momentary failure, which does not usually, at the time, cause a burnout. But the damage is cumulative as in the case of motors which are frequently started under full voltage, and the actual motor failure may occur later, during operation, and when the failure is hardest to explain.

Such a case was that of a motor driving a hydraulic elevator pump, which was started and stopped very frequently. The line terminal coil gradually became hot until it finally failed. Examination of the coil showed that it contained a large number of very small pellets of copper. A lightning arrester cannot protect against such switching surges because a lightning arrester cannot function at less than normal voltage.

BEHAVIOR OF TRAVELING WAVES

To understand the effect of lightning on motors, let us consider for a moment the behavior of traveling waves of lightning voltage. When such a wave reaches the end of an open line, it reflects to double value, so the voltage we must deal with is twice that of the traveling wave. Where we use the term surge impedance, it is, of course, the impedance to the flow of surge or traveling wave current. If we have a motor at the end of the line, we have the surge impedance of the line in series with the surge impedance of the motor, and this value of twice the traveling wave voltage divides between them in proportion to their impedances. If the surge impedance of the line is high, and the surge impedance of the motor is low, the voltage across the motor will be low.

With a surge entering one phase of a Y-connected motor, it encounters at the neutral the impedance of the other two phases in multiple, so that the voltage at the neutral is one-third of two times the voltage that entered the motor, or two-thirds of the entering wave. If the wave enters two phases, the voltage at the neutral is four-thirds the entering wave, and if waves enter all three phases, the voltage at the neutral is six-thirds, or double the wave that entered the motor. If the motor is connected delta and waves enter two or three phases, the voltage doubles at the mid-point of a phase. If the neutral is grounded, the voltage reflects but of opposite polarity; it is not doubled but is reduced in magnitude.

Therefore, we have high voltage stresses at the neutral of a Y-connected motor, at the mid-point of the phases of a delta connected motor, and at the line terminals.

If the surge impedance of the motor is equal to the surge impedance of the line, the wave entering the motor equals the traveling wave.

In a set of tests, with a traveling wave of 1000 volts, the wave entering the motor was 1600 volts, and the voltage at the neutral was 3200. If we multiply these figures by ten, we can have a traveling wave of 10,000 volts passing the line insulators, but producing 32,000 volts at the neutral of a motor.

As the wave may double, the wave entering the motor must be held to one-half the allowable impulse strength of the machine. Present lightning arresters cannot operate between this limit and normal voltage, as there is only about 6 per cent difference between these two values.

LIGHTNING ARRESTERS

When a lightning wave reaches a lightning arrester and the voltage builds up to the point where the lightning arrester functions, it limits the magnitude of the voltage, but does not affect the slope of the wave up to that point. Therefore, the wave may enter the terminal coil of a motor with excessive voltage resulting between the ends of the line terminal coils.

Lightning arresters can protect insulators. Lightning arresters alone cannot protect turn insulation.

Lightning arresters have no effect on the steepness of the wave front. Lightning arresters cannot operate on low amplitude switching surges and cannot hold the voltage down to one-half the impulse strength of the windings. We shall, therefore, have to look further than lightning arresters alone for the protection of motors and generators.

In Figure 3, we have the same motor shown in Figure 1, with the same traveling wave of 1000 volts, but a capacitor is connected between the line terminal of the motor and ground. This has reduced the magnitude of the voltage, but more important, it has reduced the steepness of the wave front. For the same length of coil as we considered in Figure 1, we then have much lower voltage between turns of the line terminal coil. We, therefore, have lower stress on the major coil insulation, and also on the turn insulation.

A crude analogy is to consider the capacitor as a bucket, permitting the flow of current to ground. Another way to look at it is this. The capacitor has low surge impedance, so in multiple with the motor, we may disregard the motor. We then have the surge impedance of the line in series with the low surge impedance of the capacitor, with the result that the voltage across the capacitor is low and consequently, the voltage at the motor is low. If you permit current to flow, you hold down the voltage, and if you prevent the flow of current, the voltage builds up. A capacitor has the ability to pass a large current when subjected to a

FIGURE 4—Cathode ray oscillogram of 80,000 volts of artificial lightning entering a system as diagrammed at the top.

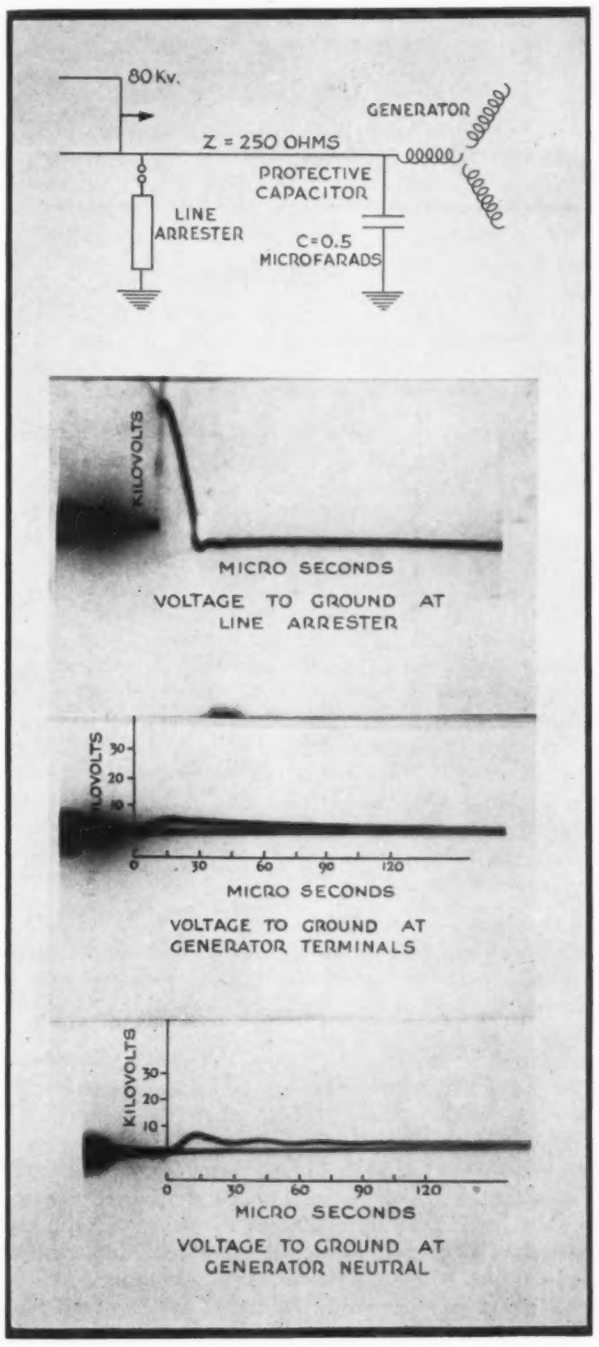
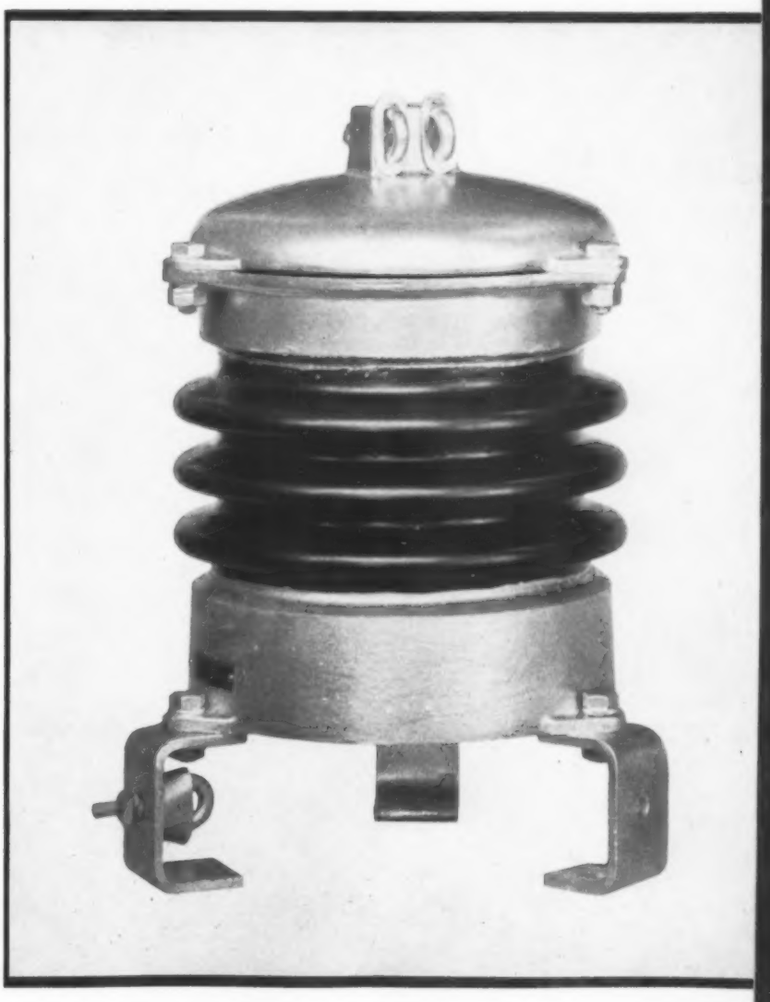


FIGURE 5—Typical station-type arrester for the protection of a-c. rotating machines.



rapid rate of rise of voltage, and to resist sudden changes in voltage across its own terminals.

In the same set of tests, where 418 volts were measured across the first turn, due to a switching surge, this was reduced to 52 volts with only .001 microfarad of capacitor connected at the line terminal of the motor to ground. If we multiply these figures by 10, we have 4000 volts on the turn insulation without the capacitor, and only 500 volts on the turn insulation with the capacitor.

Figure 4 shows cathode ray oscillograms that were taken with 80,000 volts of artificial lightning coming in over a line to which was connected a 12,500 kva., 6600 volt turbo-generator. A lightning arrester out on the line was used to limit the magnitude of the incoming voltage, which was then further reduced in magnitude

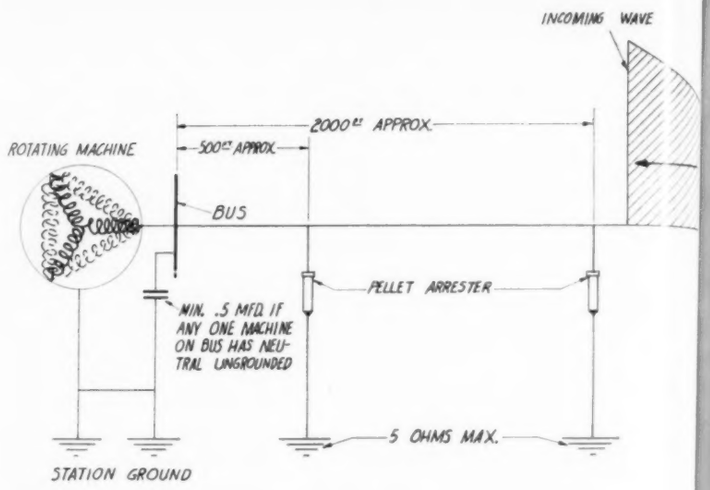


FIGURE 7—Typical connection diagram showing arresters and capacitor used for protection of rotating machine.

FIGURE 6—Protective capacitor for a 9000 volt circuit. Such units are available for motors as low as 220 volts.

and steepness by a capacitor connected at the line terminal of the generator.

It is seen from the foregoing that protective capacitors suitably combined with lightning arresters will reduce the voltage stress on insulation to a safe value.

Originally, each job of protection was tailor-made; that is, we measured the length of the turns, and the length of the iron stacking, checked the insulators on the line, and whether they were mounted on wood poles, and from this data determined what protection was needed. Now, it is standardized.

A motor can be protected by a capacitor alone if it is made large enough. We use, however, a line type arrester, 2000 feet out on the line, to act as an advance guard. It reduces the magnitude, but not the steepness of the wave. The combination of capacitor and arrester costs less than using a capacitor alone. Figure 5 shows a typical special station-type Thyrite arrester for the protection of a-c. rotating machines, and Figure 6 shows a protective capacitor for a 9000 volt circuit. Protective capacitors are available for motors as low as 220-volts and 440-volts.

The 2000 feet permits the arrester to function before the beginning of the wave reaches, and is influenced by the capacitor at the motor terminals. The 2000 feet was arrived at both by theory and tests. It allows 4 microseconds, or millionths of a second, for the lightning arrester to operate before the capacitor reduces the incoming wave. In addition, the capacitor is charged by the reduced voltage through the surge impedance of the 2000 feet of line and we use the surge impedance of the line to obtain the charging rate of the capacitor. There is nothing absolutely fixed or sacred about the distance of 2000 feet. For example, in one case the arrester was located where it could have a good ground in the bed of a stream, and in another case at a pole where two lines joined, at approximately 2000 feet. Where protection is desired against direct hits, over-

head ground wires are required over this 2000 foot area.

In applying this protection to an industrial plant, where it is difficult or impossible to obtain the 2000 feet out to the arresters on the line, it is necessary to use judgment, as each case is different. The arresters are spotted at strategic points and, if possible, overhead ground wires are used. The protective capacitors are used in any case, as the ground wire reduces the magnitude but not the steepness of the incoming wave.

Where there are transformers in the line, we use a lightning arrester on the line side of the transformers instead of using an arrester 2000 feet out, thereby utilizing the surge impedance of the transformers for the same purpose. Incidentally, this arrester serves to protect the transformer as well. There is a possibility of resonance, when a lumped capacitor is charged through a lumped inductance, and a transformer is a lumped inductance. Therefore, when there are transformers, a lightning arrester is used in multiple with the capacitor. The capacitor holds down the steepness of the wave, and the arrester holds down the magnitude. Figures 7, 8, 9 and 10 show typical connection diagrams.

Where there is a short length of cable between the machines and the overhead line, as in Figure 8, the same protection is required as if the cable were not there, as cables less than a mile in length are of little protective value especially if they are not lead covered to provide capacity to ground.

Where there are several motors or generators on a bus, even if they are connected a few hundred feet away from the bus, one capacitor may be used. Figure 11 shows such an installation. A suitable means for disconnecting should be provided, and it is very important to have a good ground connection from the ground terminal of the capacitor to the frame of the machine being protected. If this is difficult, it is preferable to have a capacitor at each machine. Good ground connections are very important.

A capacitor is connected between each phase or terminal and ground, and the ground terminal is connected to the frame of the machine, and to ground, and to the sheath of the cable if any.

The protective capacitor must be in close shunt relationship with the insulation to be protected. It is important to avoid IR voltage drop in the ground connections. These protective capacitors are made for high test voltage, and are especially wound for low inherent reactance. Essentially, we treat motors and generators alike.

In one case where there was a $10,000 expense for repairing lightning damage, they installed this form of

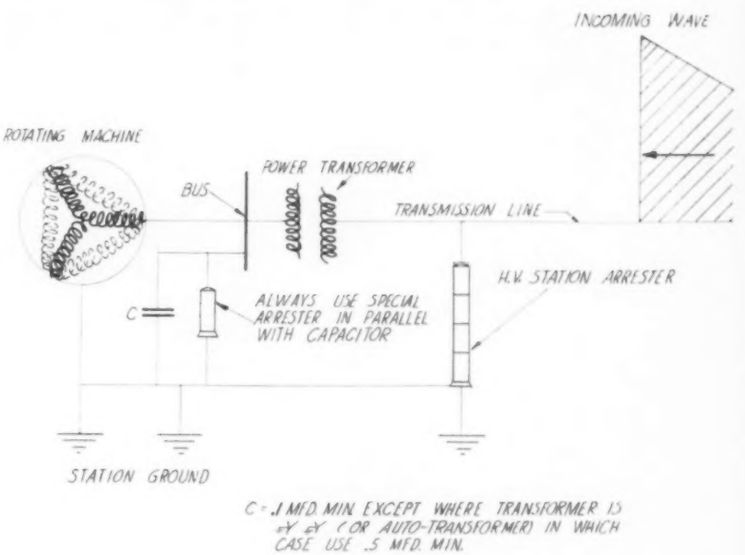

INCOMING WAVE
ROTATING MACHINE
POWER TRANSFORMER
BUS
TRANSMISSION LINE
H.V. STATION ARRESTER
C
ALWAYS USE SPECIAL ARRESTER IN PARALLEL WITH CAPACITOR
STATION GROUND
C = .1 MFD. MIN. EXCEPT WHERE TRANSFORMER IS ΔY, ΔY (OR AUTO-TRANSFORMER) IN WHICH CASE USE .5 MFD. MIN.

FIGURE 9—Where there are transformers in the line, an arrester is used on the line side of the transformers.

FIGURE 8—Short cable lengths between line and machine are of little protective value, and must be disregarded as a protective item.

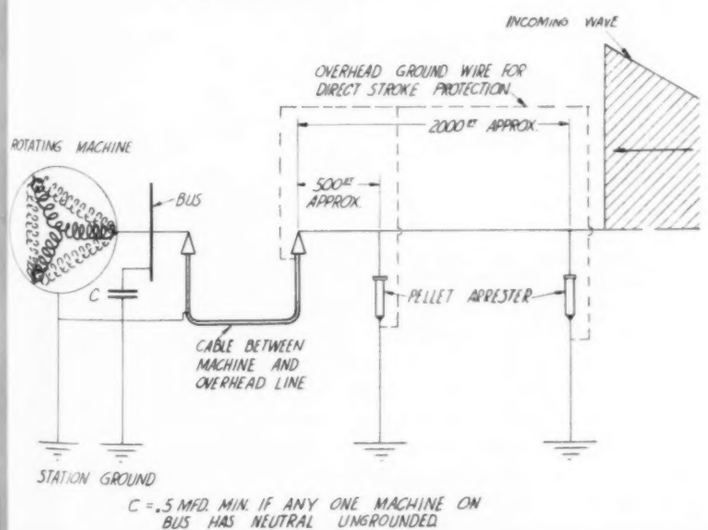
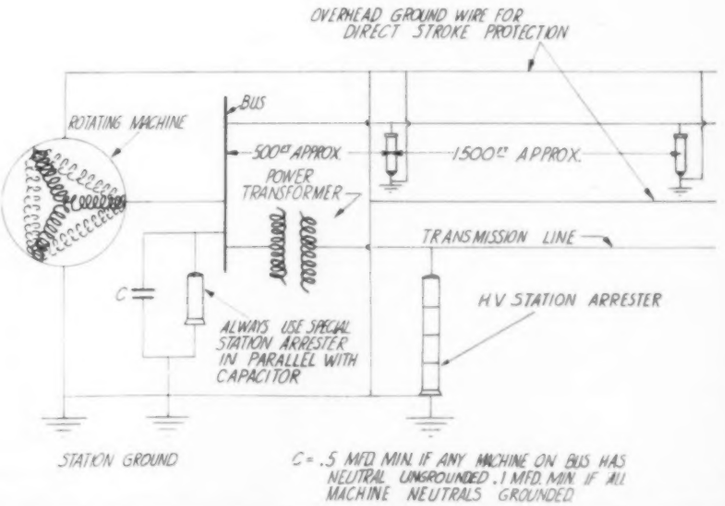


FIGURE 10—For complete protection, overhead ground wires are desirable, in addition to arresters and capacitors.


OVERHEAD GROUND WIRE FOR DIRECT STROKE PROTECTION
ROTATING MACHINE
BUS
500 FT. APPROX.
1500 FT. APPROX.
POWER TRANSFORMER
TRANSMISSION LINE
C
H.V. STATION ARRESTER
ALWAYS USE SPECIAL STATION ARRESTER IN PARALLEL WITH CAPACITOR
STATION GROUND
C = .5 MFD. MIN. IF ANY MACHINE ON BUS HAS NEUTRAL UNGROUNDED .1 MFD. MIN. IF ALL MACHINE NEUTRALS GROUNDED

protection in their three stations, and have not had any failures since. This has been in service for several years, but, of course, we do not know whether failures would have occurred without the protection; that is, to what lightning voltages the machines have actually been exposed since the protection was installed. It is important, however, to install the protection before it is too late; that is, before sufficient damage has accumulated in the coils to make them ready to fail under very slight provocation, such as a little vibration, or a little dirt, or heat. This form of protection is relatively new, but has proved its usefulness.

You are interested in keeping your plants in operation and in reducing maintenance. When a motor fails, and while it is being torn down, note the location of the failure relative to the line terminals, to the "Y" point, to the middle of the delta, whether it is outside of the iron, and whether it was a turn to turn failure. In this way, valuable information will be obtained for the application of protection to rotating machines.

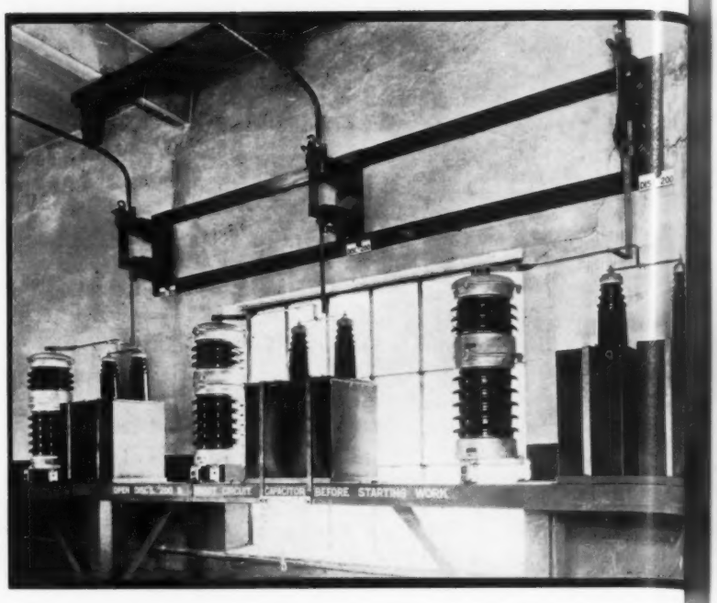


FIGURE 11—One capacitor may serve several rotating machines on one bus, even if they are connected a few hundred feet from the bus.

DISCUSSION

PRESENTED BY

A. J. STANDING,* Electrical Superintendent, Bethlehem Steel Company, Bethlehem, Pennsylvania.

W. H. BEYERLE, Assistant Electrical Superintendent, Bethlehem Steel Company, Sparrows Point, Maryland.

G. C. PFEFFER, Superintendent of Power, Florence Pipe and Foundry Company, Florence, New Jersey.

S. K. WALDORF, Test Engineer, Pennsylvania Water and Power Company, Baltimore, Maryland.

NORMAN R. COX, Electrical Engineer, Alan Wood Steel Company, Conshohocken, Pennsylvania.

L. H. FISTER, Foreman, Power and Transmission, Bethlehem Steel Company, Bethlehem, Pennsylvania.

P. J. WALTON, Application Engineering Division, General Electric Company, Schenectady, New York.

J. C. REED, Electrical Engineer, Bethlehem Steel Company, Steelton, Pennsylvania.

*Deceased.

A. J. STANDING: We have something very serious to think about. We have contented ourselves and considered we have taken quite a step forward when we were able to sell our management the idea of proper lightning arrester protection. According to the latest thought at the time we installed them as near to the stations as was possible to get them. Now, our problem is to sell the idea that this is not the final answer, that we have to have capacitors. Mr. Walton has been up the plant and has put this story across, but I wasn't altogether sold on it.

It is an interesting problem when you consider the distances that we have, as referred to before—of 2,000 feet distance from any one station to another station. Just how we can compromise on that distance and yet get the effect is a problem I would like to have answered.

Our 6600 volt would require three single-phase capacitors. We may try it out when things return to normal and we can get the appropriations. It is very interesting to realize that this capacitor introduction has such a definite effect on the voltage at the machine. We have had generators and motors which have failed in just the way Mr. Walton has indicated they should fail under these conditions. The problem, if we can work out the economics of it, is to evaluate the anticipated failures of such machines in terms of money enough to provide the capacitors for protection. I am convinced that it has a right to exist and has a real value, but as I said before our job is to sell it to the management with enough assurance to get in a sufficiently large installation to prove our point. We have had to do this with lightning arrester protection. There has been no question about that. They have proven their right to exist and the management has been thoroughly sold on the installation of arresters and they feel they have answered the bill and paid for themselves. Now, if we can get in the same position with respect to capacitors, I think we can go a long step further in our improvement, particularly to large motors and generators which we have in our system with a great deal of power behind them. It is getting to be more and more a problem as all our plants become more interconnected with greater amounts of power from various directions feeding into our system, coupled with the fact that some of our equipment has been somewhat weakened

by flood conditions which don't do it any good, and I am wondering if, under those conditions, it wouldn't be well to go to the capacitor installations, get a standard set-up of distances which will apply to any one installation in a plant.

W. H. BEYERLE: Previous to our new construction period, we had one 3000 hp. motor driving a motor-generator set supplying power for the 40″ blooming mill protected by condensers and arresters which were not more than 25 feet away from the motor. In our new construction, capacitors were installed directly under the motor in all 6600 volt, 60 cycle installations.

For some years we have considered it to our advantage in case of an approaching storm to shut down some of our principal units because we considered it better practice to lose the tonnage for a comparatively short time than taking the chance of losing the motor and thus being down for an indefinite time. Most of our storms approach from the northwest and I have noticed on many occasions that after the storm appears to have passed overhead and mills were ordered to go ahead, a sudden stroke of lightning, apparently coming from nowhere, struck our lines. This stroke we have termed "the last wham".

We cannot say from experience that capacitors will be the answer to this problem of lightning protection, but hope that it will go a long way toward doing it. I have enjoyed the lecture very much and I think that this section is to be congratulated on having the paper presented in such an able manner as we have this evening.

G. C. PFEFFER: I listened with a great deal of interest to Mr. Walton's paper. He spoke of two thousand feet of cable between the station and the motor to be protected. If that were cut down to five hundred feet and that connection made by means of lead-covered cables, would the cables act in the same capacity as a capacitor?

S. K. WALDORF: I just want to reiterate the point that Mr. Walton made that you must shield out to two thousand feet if you are going to protect station equipment. This emphasizes the importance of good shielding. It is our practice at our stations to run out not only two overhead ground wires, but three or four, or even five. It has the effect of increasing the capacitance of the line and reducing the surge voltage, in addition to the effects Mr. Walton described to you.

In our experience with arresters, we just this year started to measure the currents that occur during a lightning season. Although I do not have the full data at this moment, our observations seem to indicate that where a line is well shielded out some distance—our lines are well shielded all the way—the lightning arresters are not called upon to function. In fact, our Perryville line has operated successfully for three years now without arresters on the station transformers. This was done on the basis of our studies of lightning protection.

So, to summarize, I would say to you gentlemen' if you want effective protection, it looks as if it is important to shield your lines very well to keep the lightning off of them. You will get some induced voltages, but on your high voltage lines, 69 kv., and maybe 44 kv., and higher, you should have no trouble if you shield and ground properly.

N. R. COX: There is one question that I would like to ask. Mr. Walton's paper dealt with a-c. principle; what protection other than lightning arresters would he suggest for d-c. lines such as perhaps surface trolley or in some cases d-c. lines running between buildings for a distance of a thousand feet or more?

L. H. FISTER: There is one question I would like to ask. Mr. Walton, this evening in your discussion, I assumed that you were dealing with traveling waves, impulse waves of a fixed energy content. I was wondering, particularly referring to ungrounded system in steel mills, how effective the application of capacitors would be when subjected to sustained waves, such as we might expect from an arcing ground in which the energy content is quite high and of exceptionally low frequency; that is comparatively low when we think of the equivalent frequency of impulse waves?

P. J. WALTON: Mr. Standing brought up the question of what can be done when the distances are short. In applying this protection to an industrial plant, where it is difficult or impossible to obtain the 2000 feet out to the arresters on the line, it is necessary to use judgment, as each case is different. The arresters are spotted at strategic points, and if possible, overhead ground wires are used. The protective capacitors are used in any case, as the ground wire reduces the magnitude but not the steepness of the incoming wave.

Some years ago one authority did not have a very good opinion of the efficacy of lightning arresters, because at that time, he had not found out the function of the surge impedance of the line in the scheme of protection. Because there is a certain amount of surge impedance in the lightning arrester, if we have zero impedance in series with the impedance of the arrester, all of the voltage will be across the arrester. So the impedance of the line is necessary to obtain the greatest benefit from the protective equipment.

One question which was asked was whether 500 ft. of cable has sufficient capacity to ground to afford protection. It has been found that unless the cable is a mile or so long, we don't get much benefit from the cable. If the cable is short, you may have successive reflections building up the voltage. We do not consider that short lengths of cable give us any real protection. What we need is a lumped capacitor at the motor terminals. Distributed capacity somewhere else does not do much good, as far as protection is concerned.

In the three cases mentioned, the machines were

(*Please turn to page 67*)

RECENT ADVANCES TOWARD *Lightning* PROOF TRANSMISSION LINES

By S. K. WALDORF, Test Engineer

Pennsylvania Water & Power Co.

BALTIMORE, MD.

Presented before the
A. I. & S. E.
Philadelphia District Section
February 5, 1938

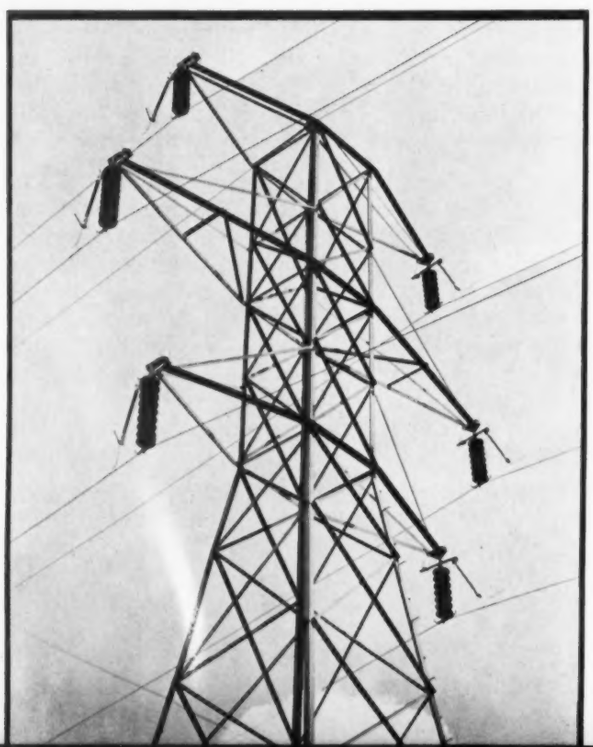
▲ LIGHTNING protection may be divided into two classes:

Remedial protection which does not prevent flashovers but minimizes their harmful effects.

Preventive protection which attempts to eliminate flashovers entirely.

In the remedial class of protection may be listed circuit breakers, arcing horns and rings, Petersen coils, and expulsion protective or de-ion gaps. The circuit breaker extinguishes an arc by interrupting the power supply as soon as possible after the arc has formed. This action, of course, affects service continuity. Arcing horns or rings are intended to prevent damage to conductors and insulators in the interval between the formation of the arc and the power interruption. These cannot be considered as entirely satisfactory, because service must be interrupted to extinguish the arc. However, the interruption may be minimized by rapid reclosure of the line breakers.

FIGURE 2—Expulsion protective gaps, placed in parallel with 69 kv. transmission line insulation, have been applied with some success.



The Petersen coil operates on the resonant principle. Figure 1 shows diagrammatically its method of connection and operation. The coil is connected between system neutral and ground. In normal operation the capacitive charging current of the three phases of a transmission line balance each other. When one of the phases becomes grounded, an unbalanced condition exists and the charging currents of the two ungrounded phases flow through the fault. As indicated in the diagram, the Petersen coil is adjusted to make its magnetizing current I_P neutralize the charging currents of the two ungrounded line conductors. This is possible because the coil current and the line charging current are practically 180 degrees out-of-phase. When such a condition exists, an arc is soon extinguished because the small residual current flowing through the arc is not sufficient to maintain it.

The Petersen coil is not an ideal method of protection because it has certain fundamental limitations. As its operation depends upon an equality of line charging current and coil magnetizing current, readjustment of the coil is necessary whenever system operating conditions require a change in the length of transmission line connected to the coil. The coil will not be effective for phase-to-phase short circuits, only for phase-to-ground faults. As the voltage of the neutral point of the system rises to phase voltage above ground under fault conditions, transformers, lightning arresters, and insulation must be sufficient to withstand greater voltage than they experience in normal operation. Due to the resonant condition, switching surges are liable to occur, so Petersen coils must be provided with short-circuiting switches. If a fault persists for more than a few seconds, these switches are also arranged to cut out the coils and allow the line breakers to function. These coils have

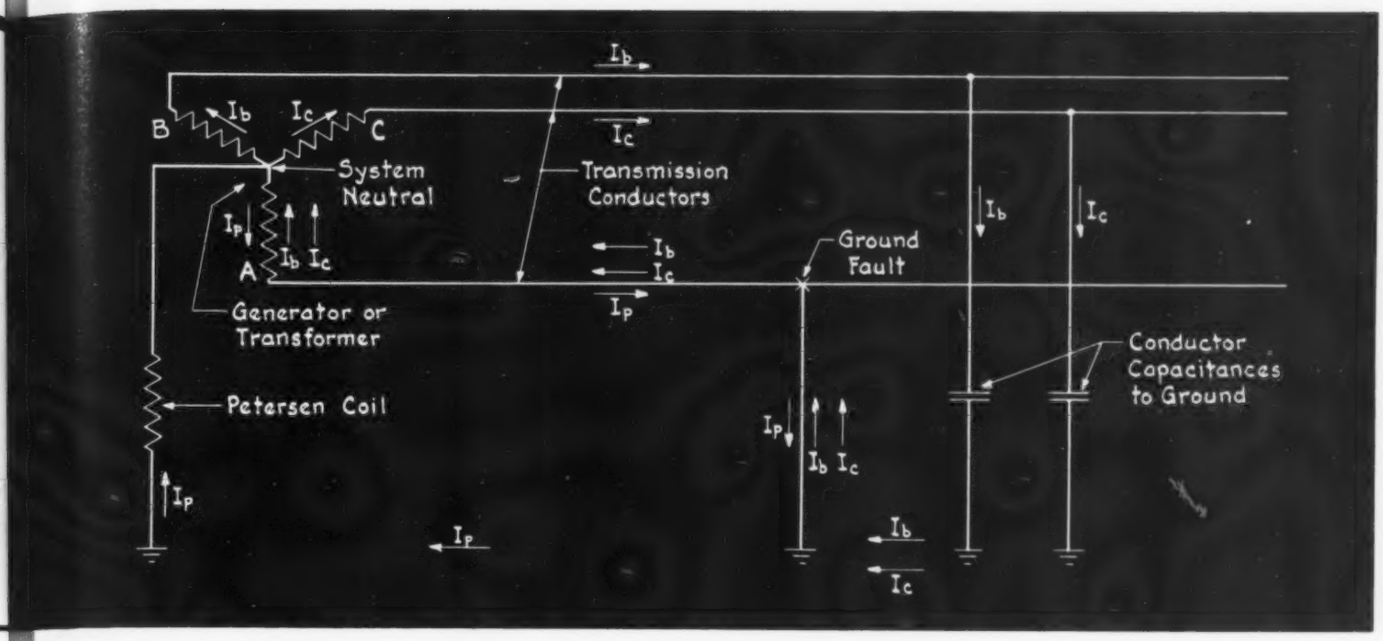


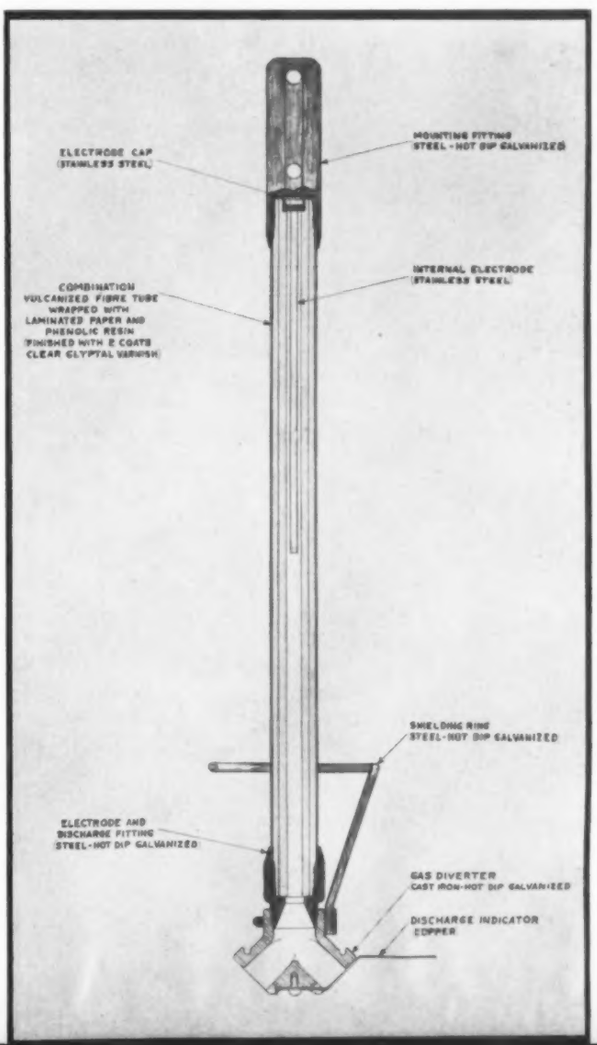
FIGURE 1—Diagrammatical presentation of the method of connection and operation of the Petersen coil.

been used extensively abroad and only recently have been utilized to any great extent in this country. It is claimed that 70 per cent of line faults are phase-to-ground and can be cleared by a Petersen coil without system disturbance. Thus, the Petersen coil offers the possibility of improving transmission line operation in some cases but because of fundamental shortcomings, it cannot provide perfect service continuity.

Expulsion protective or de-ion gaps have been applied to transmission lines with some success although their record is not perfect. Figure 2 shows gaps applied to a transmission structure. They are placed in parallel with the line insulation and their flashover value is less than the strength of the insulation to be protected. When over-voltage appears across the insulation, any resulting flashover occurs across the gap within the tube shown in Figure 3 and the series external gap. The arc being confined within the fibre tube builds up a high pressure which is released by the escape of the arc gases through the tube openings with explosive violence. The power arc is, therefore, literally blown out by the dissipation of the ionized gases.

There have been some difficulties in the application of these tubes which are gradually being eliminated. However, there are several inherent characteristics which prevent them from giving ideal performance. The tubes require that the current through the arc be sufficient to develop explosive pressures for the expulsion of the arc gases and the disruption of the arc. Therefore, the short-circuit currents at any particular installation must be limited in range. If the currents are too small, the arcs will not be extinguished promptly. If they are too great, the tube will be damaged by excessive burning or may even explode. As lightning often causes a number of strokes in rapid succession, a number of tubes may operate simultaneously, the fault current divide between them and the arcs not be extinguished. The line circuit breakers then must act to clear the faults and interrupt service. Another diffi-

FIGURE 3—Cross-section of 69 kv. expulsion protective gap. Flashover from over-voltage occurs across the gap within the tube.


ELECTRODE CAP (STAINLESS STEEL)
MOUNTING FITTING STEEL - HOT DIP GALVANIZED
INTERNAL ELECTRODE (STAINLESS STEEL)
COMBINATION VULCANIZED FIBRE TUBE WRAPPED WITH LAMINATED PAPER AND PHENOLIC RESIN FINISHED WITH 2 COATS CLEAR GLYPTAL VARNISH
SHIELDING RING STEEL - HOT DIP GALVANIZED
ELECTRODE AND DISCHARGE FITTING STEEL - HOT DIP GALVANIZED
GAS DIVERTER CAST IRON - HOT DIP GALVANIZED
DISCHARGE INDICATOR COPPER

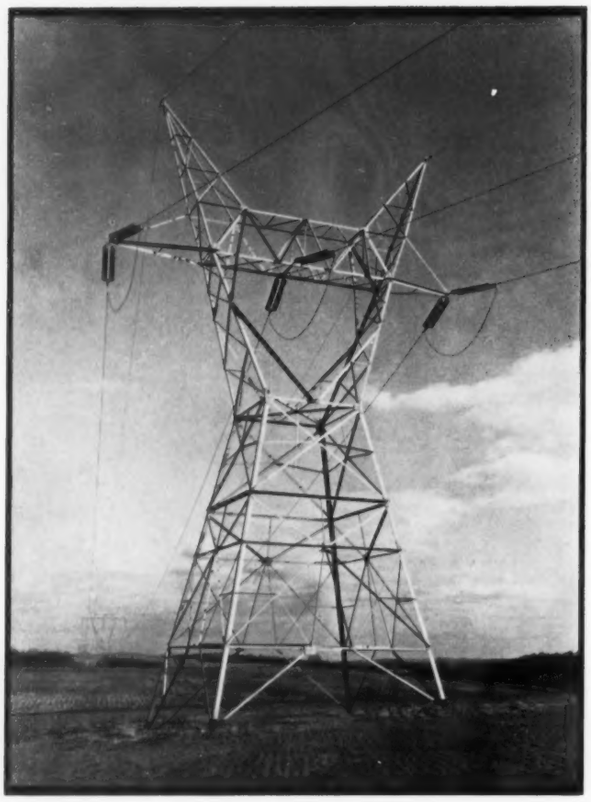
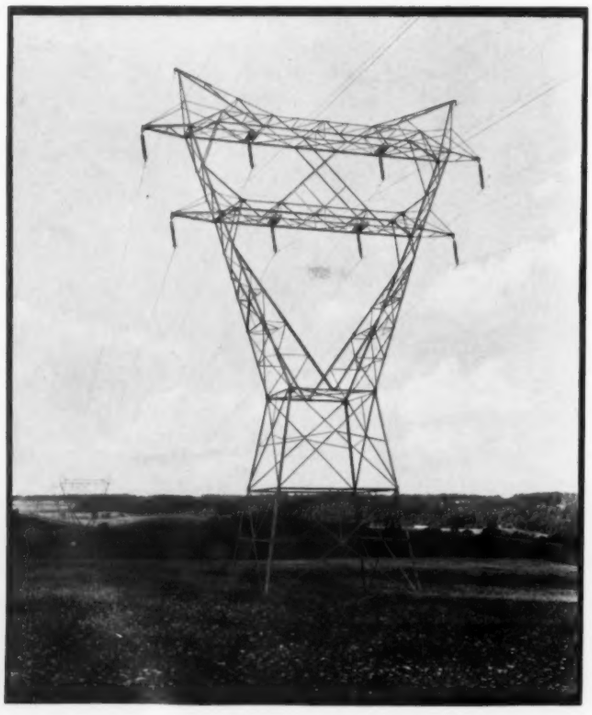


FIGURE 4—Single circuit, horizontal configuration, strain tower of 230 kv. line with two overhead ground wires.

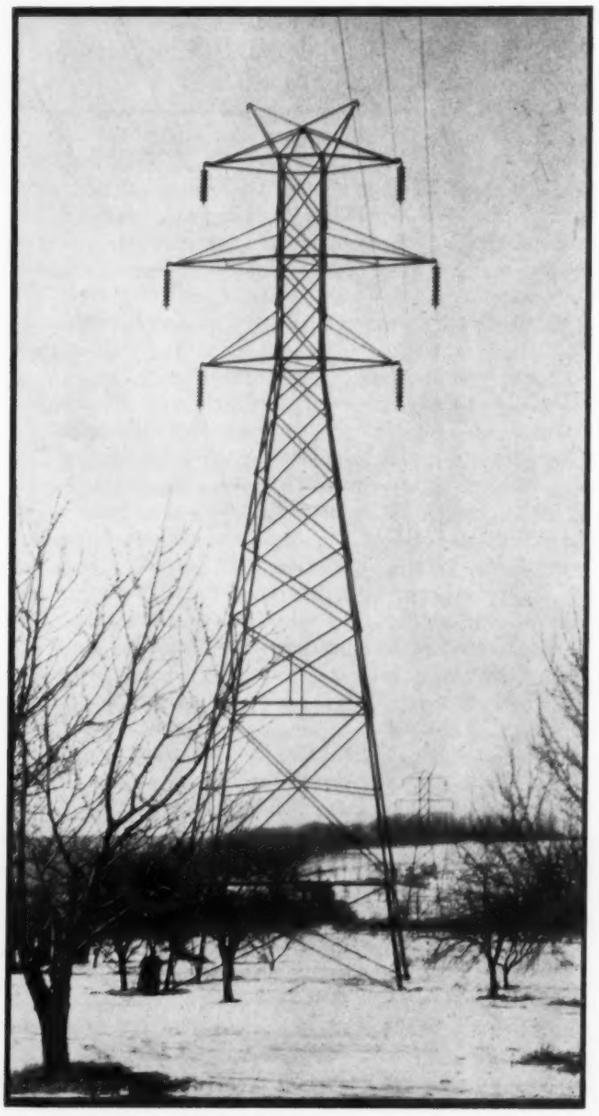
FIGURE 5—Suspension tower with four 132 kv. single phase circuits and two overhead ground wires.



culty that is appearing in gap installations is the gradual enlargement of tube bore caused by repeated tube functioning. The fibre tubes enclosing these gaps are gradually eroded so that the normal line fault current is no longer sufficient to build up the gas pressures necessary for correct operation. Expulsion protective gaps, like Petersen coils, are useful for lightning protection when properly applied, but they too cannot offer the possibility of ideal conditions because of inherent unfavor able characteristics.

Logically, the best type of lightning protection is that which will entirely prevent arc formation. This preventive mode of protection involves the shielding of line conductors by overhead ground wires from direct strokes and coordination of line insulation, conductor clearances, and tower ground resistances. The shielding provided by the overhead ground wires must be such as to intercept all strokes terminating on the line.

FIGURE 6—Tower carrying two 69 kv. circuits, with two overhead ground wires.



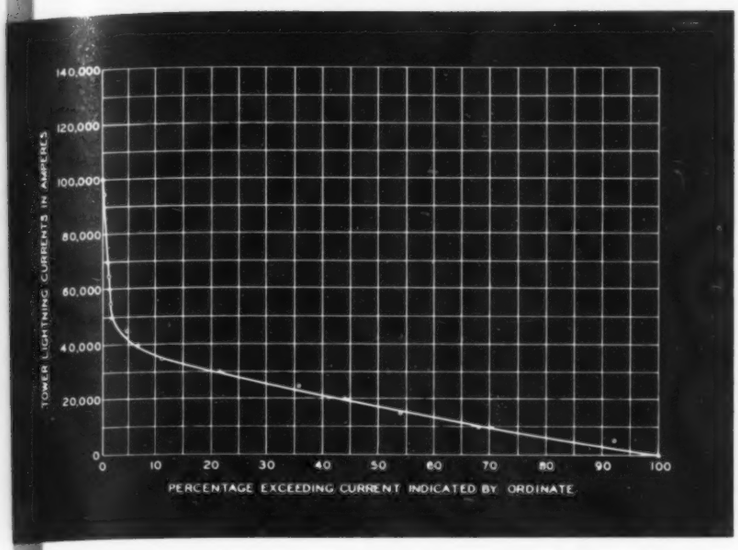
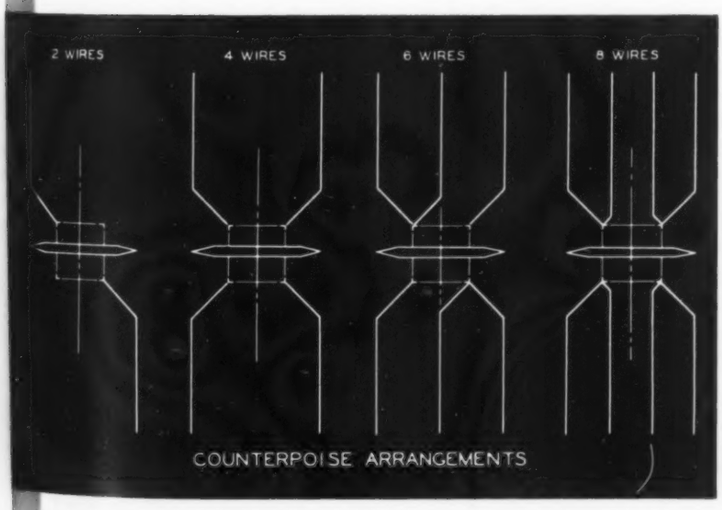


FIGURE 7—Distribution of 419 lightning currents measured in towers of various transmission lines.

Shielding against vertical strokes can be provided relatively easily, but lightning often follows an erratic path and approaches a transmission line from the side. A single overhead ground wire cannot take care of all such possibilities, but laboratory tests and operating experience have shown that two overhead ground wires can be so placed as to be practically perfect in effectiveness.

In addition to providing shielding, overhead ground wires have two other effects. First, they increase the capacitance of a line conductor to ground and thereby cause an apparent increase in the insulation strength of the line, as expressed by the coupling factor. The second effect of the overhead ground wires is to reduce the surge impedance of the towers. A single conductor in air has an initial surge impedance of about 500 ohms. Thus, a single overhead ground wire on a line has a surge impedance of about 250 ohms, as it extends in two directions from the point of incidence of any lightning stroke. With two overhead ground wires the effect of surge impedance is that equivalent to 4 conductors in parallel, or 125 ohms. Therefore, overhead ground wires are helpful in three ways: they shield the line conductors against direct strokes, apparently increase the insulation strength, and provide additional paths for dissipation of a lightning discharge. Figures 4, 5, and 6 show how well shielded lines in different voltage classes have been constructed by the Pennsylvania Water and Power Company.

FIGURE 8—Methods of installing buried counterpoise ground wires. A number of conductors in parallel is more effective than a single length.



The second consideration in the preventive method of lightning protection is line insulation. The flashover value of an insulator string has a very definite time characteristic. That is, the rapidity with which voltage is applied determines the minimum flashover value. To illustrate, 10 standard 10-inch diameter, $5\frac{3}{4}$-inch spacing suspension insulators in a string will withstand 820 crest kv. of 60-cycle voltage, 930 kv. in a standard $1\frac{1}{2}$ x 40-micro-second wave, and 1205 kv. in a standard 1 x 5-microsecond wave. Observation has shown that lightning discharges are relatively slow processes, although their duration is much shorter than that of a 60 cycle wave. Therefore, the effective insulation strength is that obtained under impulse conditions. The 1 x 5-microsecond wave imposes conditions probably more severe than that existing when lightning strikes a tower. It is felt that the flashover characteristics of insulator strings obtained with a $1\frac{1}{2}$ x 40-microsecond wave fairly approximate those effective under field conditions.

The third consideration in preventive protection is that of grounding. Measurements of lightning currents in transmission towers have shown that flashover of a shielded line usually occurs only when the product of tower current and tower footing resistance exceeds the flashover strength of the line insulation. The great majority of lightning currents are relatively small and heavy currents are rare. When a large number of observations are made and the current values plotted against the percentage of cases exceeding these values, a smooth curve is obtained as shown in Figure 7. From this curve it is possible to determine on a statistical basis just what footing resistances are needed on a given line to obtain a desired immunity to lightning.

Tower footing resistance is usually taken as a measure of grounding conditions. The ground resistance of a tower must be taken as that of the region relatively near the tower, often a long buried conductor connected to a tower will show an apparently low ground resistance when measured by ordinary methods. However, under surge conditions only that conduction near the tower base is effective in dissipating the lightning charge. Experiments have shown that the initial surge impedance of a buried conductor is about 150 ohms, reducing to the leakage resistance to ground in a few microseconds. If soil resistivity is high, and the resistance to ground of a single counterpoise conductor is too great, connecting several such conductors in parallel at the tower base will reduce this initial surge impedance. A number of counterpoise conductors in parallel is, there-

fore, more effective than the same amount of wire used in one length. Driven ground rods have rarely been found satisfactory. Figure 8 shows the way in which counterpoise wires have been installed by the Pennsylvania Water and Power Company. The number which has been used has ranged from 2 to 8, and their lengths have varied from 200 ft. to span lengths.

The Pennsylvania Water and Power Company has had very encouraging operating experience with its three lines protected by the preventive method. The Safe Harbor-Westport-Takoma 230 kv. Line, which is 90 miles long, has been in operation for six years with only one trip-out due to lightning. The Safe Harbor-Perryville 132 kv. Line, which is 31½ miles long, has been in operation for three years without any interruption due to lightning. The Holtwood-York 69 kv. Line, 22¾ miles long, has been in operation with preventive protection for 2¼ years with 2 tripouts due to lightning. With the experience gained with this line, it seems possible to improve 69 kv. lines further. As ample insulation is one of the requirements of preventive protection, there is an economical limit in applying the method to lines operating at lower voltages. This limit has not yet been determined.

In recent years three methods of protecting transmission lines against lightning have been receiving attention. Both Petersen coils and expulsion or de-ion protective gaps have their field of usefulness. For the highest grade of lightning protection the preventive type offers most. It provides protection not only for the line, but also reduces the stresses imposed upon terminal equipment. Overhead ground wires, adequate insulation, and reduction of tower footing resistances with counterpoise have been very effective in practice for transmission lines operating at voltages as low as 69 kv.

Appended is a brief list of papers on lightning protection for transmission lines. Each article has been selected as covering the latest available information on its respective phase of the subject.

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Part I—"*Overhead Ground Wires and Tower-Footing Resistance*"

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2. A. I. E. E. Committee Report, "*Modernization of Transmission Lines*", Electrical Engineering, Vol. 55, No. 1, January 1936, pp. 12-18.

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4. Griscom, S. B., and Torok, J. J., "*Keeping the Line in Service by Rapid Reclosing*", Electric Journal, Vol. 30, No. 5, May 1933, pp. 201-204.

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Peterson Coils—6. Hunter, E. M., "*Some Engineering Features of Petersen Coils and Their Application*", Electrical Engineering, Vol. 57, No. 1, January 1938, pp. 11-18.

Expulsion Gaps—7. Rudge, W. J., Jr., and Wade, E. J., "*Expulsion Protective Gaps*", Electrical Engineering, Vol. 56, No. 5, May 1937, pp. 551-557.

Preventive Protection—8. Foust, C. M., and Lewis, W. W., "*Lightning Investigation on Transmission Lines—VI*", Electrical Engineering, Vol. 56, No. 1, January 1937, pp. 101-106, 189.

9. Waldorf, S. K., "*Probable Outages of Shielded Transmission Lines*", Electrical Engineering, Vol. 56, No. 5, May 1937, pp. 597-600.

10. Bang, A. F., and Hansson, E., "*Lightning-Proof Transmission Lines*", Electric Light and Power, Vol. 16, No. 1, January 1938, pp. 48-51.

Line Insulation—11. E. E. I.—N. E. M. A. Committee Report, "*Flashover Characteristics of Rod Gaps and Insulators*", Electrical Engineering, Vol. 56, No. 6, June 1937, pp. 712-714.

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Overhead Ground Wires—13. Conwell, R. N., and Fortescue, C. L., "*Lightning Discharges and Line Protective Measures*", A. I. E. E. Trans., Vol. 50, No. 3, Sept. 1931, pp. 1090-1100.

14. Reference 10.

Counterpoise—15. Hansson, E., "*Practical Applications of the Counterpoise*", Electric Journal, Vol. 33, No. 6, June 1936, pp. 281-285.

DISCUSSION

PRESENTED BY

A. J. STANDING*, Electrical Superintendent, Bethlehem Steel Company, Bethlehem, Pennsylvania.

L. F. COFFIN, Mechanical Superintendent, Bethlehem Steel Company, Sparrows Point, Maryland.

R. M. FULLER, Consulting Engineer, Riverton, New Jersey.

G. H. SCHAEFFER, Chief Electrician, Carpenter Steel Company, Reading, Pennsylvania.

W. H. BEYERLE, Assistant Electrical Superintendent, Bethlehem Steel Company, Sparrows Point, Maryland.

G. W. SPAULDING, Assistant Chief Engineer, Pennsylvania Water and Power Company, Baltimore, Maryland.

L. H. FISTER, Foreman, Power and Transmission, Bethlehem Steel Company, Bethlehem, Pennsylvania.

H. N. EKVALL, Engineer, Lightning Protection Group, Philadelphia Electric Company, Philadelphia, Pennsylvania.

S. K. WALDORF, Test Engineer, Pennsylvania Water and Power Company, Baltimore, Maryland.

*Deceased.

A. J. STANDING: I came here tonight for the express purpose of learning something which we could take home for practical use, and I am glad to say that has been accomplished. I think Dr. Waldorf has put a highly theoretical discussion into few words and very practical and concise form. To my mind it boils down to ample shielding and ample grounding, both of which is within the reach of industrial plant lines. I might say that our industrial plant lines have a different problem in that we are closely coupled, short lines with considerable power—we do not have the advantages that we would with longer lines, which changes our problems to a certain extent. We have derived some benefit from improved grounding.

One particular case which I might cite is our cinder dump area which is in itself a tremendous insulator and experienced a considerable amount of lightning trouble until we put a very large copper ground wire over the cinder dump line and imbedded grounds in a creek that runs underneath the original cinder dump with a good net work of copper wires in the bed of the creek. That was a small step in the direction Dr. Waldorf has indicated and we have derived considerable improvement because our cinder dump line has been practically immune.

The second thing that we have to accomplish, I have learned from Dr. Waldorf tonight, is the continuation of shielding and grounding. I think it is unquestionably true that a great many of our towers have unusually high resistances and the step I believe it would be worth while for us to take is not only to go to the counterpoise idea, but we might tie our lines in with the steel construction of the buildings which would give us the benefit of a very good ground. That, together with additional shielding, is something which I believe will help us, although we have improved year by year along this line. We have had similar trouble with ground wires originally put up which were too small and in time corroded, tore off and fell down causing their own series of troubles. We have gone to very fairly large size copper-clad steel and in some cases we have gone to copper cables, but that is, however, quite expensive. Copper-clad steel makes a good rugged ground line which is universally successful.

L. F. COFFIN: To a member. who is non-electrical, this paper has been most interesting. I would like to ask what is the material usually used in counterpoise wires, and the approximate depth to which they are buried in the ground?

R. M. FULLER: Is it true that the frequency of lightning storms follows the periods of sunspots, supposed to be something like seven years, in intensity from minimum to maximum?

GEORGE H. SCHAEFFER: I am very glad I had the privilege of hearing this paper. Several questions developed during the lecture. I would like to know what definition he gives to an outage. It seems remarkable, at least to me, that a transmission line would go three or four years without an outage. I certainly feel that way about it and I hope that an outage is what we consider an outage. Another thing I would like to ask is whether, regardless of the length of the transmission line, he recommends counterpoise plus a ground line. I would also like to know why he ran four single phase lines down to Perryville, especially since there is no danger of an outage; why were there four pair of wires run down there? I want to commend the author on this interesting paper.

W. H. BEYERLE: The lecture as presented this evening was very interesting and ably executed and understandable in a measure, even to those who have not had very much, if any, transmission line experience. In large industrial plants, as Mr. Standing brought out, we have a problem of comparatively short transmission lines of rather low voltage and with feeders of large circular mil capacity and with tremendous capacity behind them. In addition to this, synchronous apparatus generally used on motor-generator sets for generating low voltage d-c. power for mill motor drives act as condensers in case of line disturbances and contribute to the confusion in case of failures. Our old system in the plant which is a 6600 volt, 25 cycle, system, is protected by lightning arresters and in some cases zero or static lines are suspended above the circuits on the transmission towers. We have, on several occasions, found these zero lines to burn down and cause more trouble than if they had not been there.

In the new 6600 volt, 60 cycle system which supplies power to our new mills, the transmission lines are protected by two $\frac{3}{8}$ inch copper-clad static lines and suspended in such a way that we hope to find that they will add greatly in protecting the transmission lines from lightning strokes.

G. W. SPAULDING: I don't believe that I have anything to add to Dr. Waldorf's paper. While I am familiar with the excellent work Dr. Waldorf has been doing for our company and the industry to improve lightning protection on high voltage transmission lines, I have not been directly associated with Dr. Waldorf in the work described to you this evening. I might however answer one of the questions which has just been asked that did not pertain strictly to the theory of lightning or lightning protection.

One of the previous gentlemen asked why four circuits had recently been built between Safe Harbor and Perryville in view of the excellent operating record on several of our other circuits. These four circuits operated at 132,000 volts and are for the supply of single phase power to the Pennsylvania Railroad's electrification. These multiple circuits were built at the request, and to meet the specific operating requirements of the Pennsylvania Railroad as a part of its extensive transmission network.

The railroad now has two circuits on its railroad structures extending from its several points of power supply in the Philadelphia area to Washington. The railroad's plans at that time also provided for two additional circuits between Philadelphia and Washington at some future date. The two present circuits however are normally sectionalized at Perryville, with the northern section of these circuits connected to two of the four Safe Harbor-Perryville circuits, while the southern sections are connected to the other two Safe Harbor Circuits. All four of these Safe Harbor-Perryville circuits are normally in parallel on the low

tension bus at Safe Harbor. There is then a source of power supply to the railroad's transmission system at Lamokin near Chester, another in Washington and a third source at Perryville over the 30-mile transmission line from Safe Harbor.

Because of the reliability of these circuits against lightning disturbances, we felt justified in taking advantage of the economies from building all four circuits on a single tower structure rather than building two transmission tower lines as are frequently seen today where four circuits are required.

G. H. SCHAEFFER: That doesn't answer my question. That only united them up to the power house. Why couldn't they be switched right at the railroad?

G. W. SPAULDING: It was a matter of operating expediency rather than one of operating reliability. It would take too long to go into all of such details, but I think that perhaps answers the question.

L. H. FISTER: As a non-member I have certainly enjoyed Dr. Waldorf's paper a great deal. We have applied some of his principles at Bethlehem and we have had some success. I can still recall several other phases which we continue to apply, such as the principle of shielding.

H. N. EKVALL: We have been interested in sunspot cycles from the standpoint of trying to predict seasonal thunderstorm intensity. However, we have found no correlation between storm intensity and sunspots. Approximately every third or fourth year we have a severe lightning season, whereas the peaks of the sunspot cycles occur approximately every eleventh year.

There is one question I would like to ask Dr. Waldorf: Is there any advantage in lowering the ground resistance on towers on which tube protection is applied?

S. K. WALDORF: I don't remember all the names of the men who asked questions, so I shall just give each question as I have it and the answer as I think it ought to be or as I can give it.

About the types of overhead ground wires that we are using. The new lines have aluminum conductors, steel-reinforced, and the last line that we have constructed is using high-strength copper-clad conductor, rather small in diameter. There are others with galvanized high-strength steel as an experiment to see how it is going to last.

The next item is some comment about grounding lines or towers to steel station structures. That is a good idea, but you must be sure that your building is well grounded too because lightning strokes very often have a great deal of energy in them. If one strikes any one of a group of structures having a poor ground resistance, it may raise the potential of all of them to a dangerous level. This will be hazardous for anyone who may be around, so you must do bonding with discretion.

One of the questions that might be brought up in your minds is just how far can we go in protection with overhead ground wires and counterpoise? Our experience so far is that we can go down to 69 kv. We have had an outage per year on a well protected 69 kv. line, and we feel that with the experience we have had, we can make that line lightning-proof with a little more money spent on it. Whether that will be done, I don't know.

One question was, "How do we know when an expulsion protective tube has operated?" As I indicated to you on one of the slides, some of our tubes have a strip of copper painted yellow partially covering one of the tube outlets. When an operation occurs, the explosion blows this piece of metal downward and sometimes completely off of the tube, giving an indication. Another type of indicator which we have is a thin piece of wire put around the tube. This wire has a tag on it which can be seen from the ground and if it disappears, we assume a tube discharge has occurred.

Another question referred to the counterpoise material we use and to what depth it is buried. The general classes of material used are copper and copper-clad steel. The copper has been in the form of hot-rolled one-quarter inch rod and 2/0 stranded conductor, the latter used because it was discarded line conductor. The copper-clad steel has been solid 1/0 conductor, used on the Perryville Line.

A. J. STANDING: What would be the effect of using scrap crane cables?

S. K. WALDORF: I don't think that all-steel cable would make any difference electrically, but it might corrosively. It probably would not last very long, but be otherwise satisfactory.

I think that Mr. Ekvall answered the question about sunspots very well. As far as I know, no connection has yet been discovered between sunspots and lightning storms.

A definition was asked for an outage. As I used it here and as we usually use it in speaking about lightning protection, it means an unexpected interruption of service. That is, if you are going along and expecting power to be there, and it is cut off without any previous notification, we call that an outage when we speak of it in connection with lightning.

G. H. SCHAEFFER: It has no relation to time then?

S. K. WALDORF: You mean, how long? If it is interrupted for just an instant, if the power goes off for only a few cycles, that is an outage.

G. H. SCHAEFFER: You would call it an outage even if it wouldn't shut down any machinery or wouldn't knock the synchronous motors off?

S. K. WALDORF: If the circuit breaker acts to interrupt the power, we call that an outage. If one of these very high-speed reclosures which we are speaking about occurs, we call that an outage. If the reclosing device puts out an arc and recloses very rapidly, so fast that a synchronous motor might stay in step, depending upon its loading, we call that an outage.

G. H. SCHAEFFER; The customer might never know it then?

S. K. WALDORF: That's true, but we would call that an outage.

There is another question that I am not quite sure about which came from the same gentleman, about counterpoise and overhead ground wires. Just what was that?

G. H. SCHAEFFER: I asked whether you would put them in regardless of the length of the line. I believe Mr. Standing mentioned some of his short lines. I was wondering whether you would put them in, say they were ordinary short lines.

S. K. WALDORF: The idea is that they will function on a short line, even though it is just a few miles long. Their installation depends upon how important the service is, keeping in mind that their use has not yet been worked out economically for less than 69 kv. tower lines.

I think Mr. Reed mentioned the question about the ground of the lines being connected to the ground of the generators. Generator grounds are usually connected to station grounds, and if the latter are found to be low by the usual methods of measurement, transmission lines may be connected to them. It is our practice to connect overhead ground wires and counterpoise to station grounds, thereby connecting line grounds and generator grounds together.

Mr. Ekvall, I believe, asked the question about the effect of ground resistance of a line on protective gap protection. These tubes depend upon the short-circuit current for building up tube pressures to extinguish the arc. By improving grounding, tube operation is sometimes improved, because the fault current is increased and the arc blown out more rapidly. However, certain types of tube installations function properly without good line grounding.

I believe that those are all of the questions, but if there are any more or any that I didn't answer satisfactorily, please say so.

MEMBER: I would like to ask Dr. Waldorf, having considerable experience on copper-clad steel and his counterpoise and his overhead grounds, does he depend on the copper-clad or the steel to carry that conductor of current, or does he figure on the copper-clad wire, of the conductivity of that copper-clad, as that of copper?

S. K. WALDORF: The conductivity of our copper-clad steel is 30 per cent. We consider that good enough. The reason we have the copper on is to give some conductivity and to protect the steel from rusting.

MEMBER: You don't depend on the copper then for the carrying capacity of your underground counterpoise?

S. K. WALDORF: We take the thing as a conductor, made up of two kinds of material. We just consider the conductor as a whole.

MEMBER: I have tested that copper-clad as high as 60 per cent and 80 per cent that of copper and was wondering whether you depend on the conductivity of that copper-clad to take the place of the copper of your underground counterpoise?

S. K. WALDORF: I am not sure that I understand the question. We think that the material we use is adequate to carry the surge current without difficulty.

MEMBER: If you would use a greater amount of copper on your steel and use a smaller wire, would that answer the purpose, instead of using a large wire of a copper-clad nature?

S. K. WALDORF: Our copper-clad wire is larger in diameter than our plain copper wire. It is five-sixteenths inch copperweld, one-quarter inch copper. The reason that we used copperweld is that people like to steal copper. We felt that copper-clad is hard to cut and also that anyone trying to sell it would not get a very good price for it. That would discourage further thefts

MEMBER: Have you also taken into consideration, when you are using that as an overground wire, to prepare a greater tensile strength?

S. K. WALDORF: We are using only a small wire, three-eighths inch. We depend on the additional strength that the steel provides. We believe that it will be adequate.

BALLARD DISCUSSION

(*Continued from page 41*)

troubles may be attributed to lubrication often results in the lubricant being blamed for difficulties caused by mechanical or construction conditions entirely independent of the oil or grease in service.

With reference to Mr. Thomas' remarks regarding unfiltered vs. filtered oils for use in circulating systems on pinions and reduction gears, it is true that the oil in such systems is not subjected to excessive contamination, but the fact remains that a filtered oil possesses better oxidation as well as demulsibility characteristics than an unfiltered oil of the same type and viscosity and in the long run will give a longer useful life before a complete change is necessary. On the other hand the cost of a filtered oil is usually higher than that of an unfiltered oil of the same viscosity and it is a question of economics involving also the make-up required whether the greater first cost of the filtered oil will be offset by its possible longer life. Where extreme pressure or high film strength oils are essential there must be some sacrifice in demulsibility properties with most of the currently available products possessing such characteristics, but it is highly probable that in the near future material improvements will be made in the oxidation stability and demulsibility of high film strength oils for use in circulating systems.

Mr. Walter's and Mr. Maag's comments are of interest and represent a valuable addition to the paper. The various points raised regarding prevention of contamination, cleanliness, frequent inspections and the application of some of the newer lubricants to older installations are self-evident and require no further comment.

PICKLING of Strip STEEL from the METALLURGICAL POINT of VIEW

By H. P. MUNGER, Metallurgist

REPUBLIC STEEL CORP.

WARREN, OHIO

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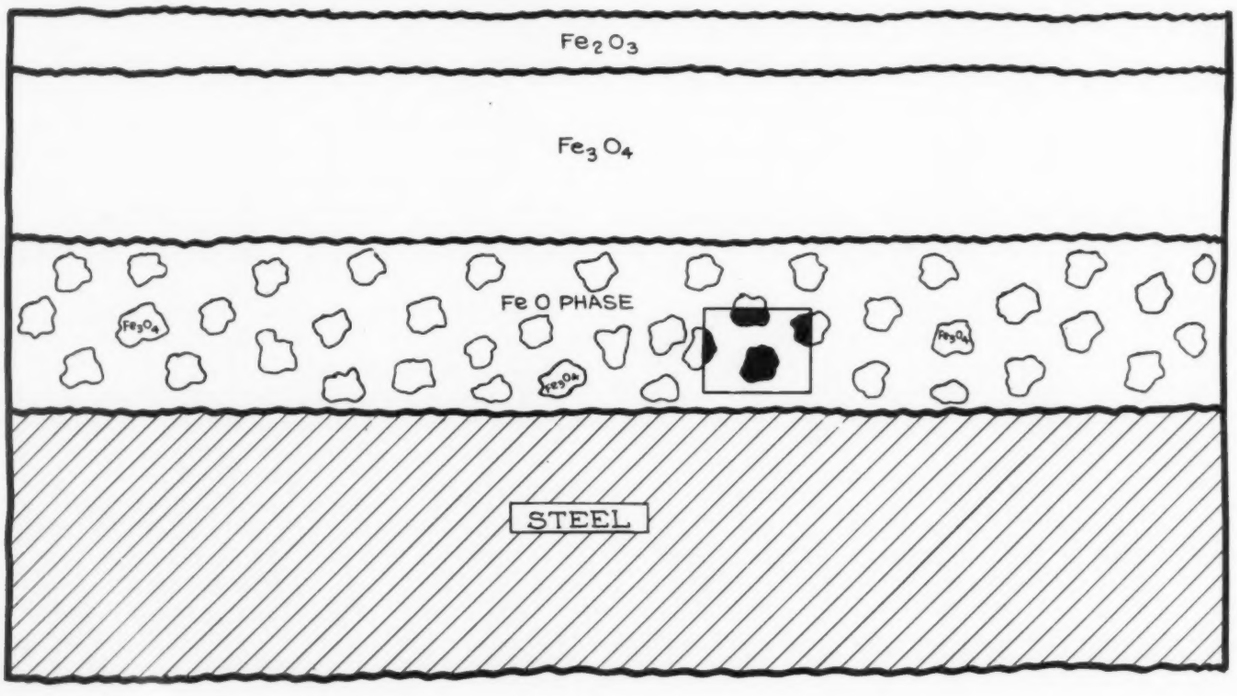
▲ IN hot working steel, a scale is formed which it is usually necessary to remove for further processing or for use. It is customary to remove this scale by pickling in an acid solution. For certain purposes the scale is sometimes removed mechanically by sand or shot blasting. This method of scale removal is not widely used on strip steel and will not be discussed here.

Before discussing the pickling process, it should be of interest to consider the properties of the scale which is formed on steel and their effect on the pickling process. A large amount of work has been done on the nature of the scale which is formed under various conditions and a bibliography of this work is found elsewhere (1).

(1) H. P. Munger, Trasn. Am. Electrochem. Soc. *69*, 85 (1936).

(2) L. B. Pfeil, J. Iron Steel Inst., *119*, 501 (1929); *123*, 237 (1931).

FIGURE 1—Scale is commonly accepted to be made up of three separate layers, the degree of oxidation increasing toward the outer surface.



H. P. MUNGER

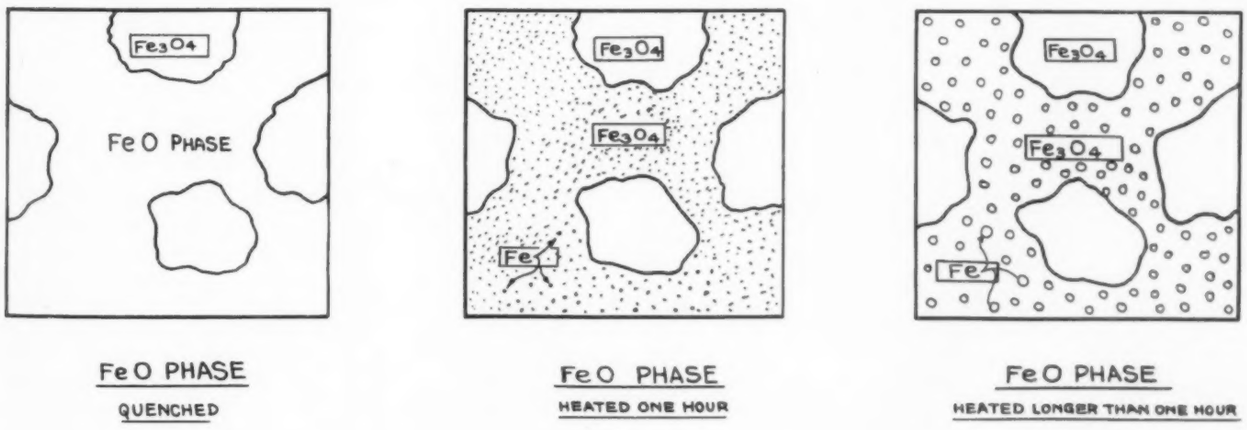
In the study of the oxidation of steel in air, Pfeil [2] has shown that the scale consists of three layers (Figure 1). The outermost layer is approximately Fe_2O_3, has a velvety appearance and a black glassy fracture. The middle layer is magnetic iron oxide, Fe_3O_4 which is black and has a crystalline fracture. The layer next to the base metal, approximately FeO in composition, is porous and consists principally of minute cubic crystals. Since FeO decomposes during cooling at about 1,065 degrees F. (574 degrees C.), this phase consists principally of Fe_3O_4 crystals, precipitated from the solid solution above this temperature, in a matrix of very finely divided iron in Fe_3O_4.

The dispersion of iron in the normally cooled ferrous oxide phase is such that it is vigorously attacked by dilute acid (0.1 per cent HCl). Pfeil [2] found that when the scale is quenched from above 1,065 degrees F. (574 degrees C.), it is only slowly attacked by even strong acid (75 per cent HCl) (Figure 2). When quenched samples are heated at 1,020 degrees F. (549 degrees C.) for 10 minutes the rapid solution phase (that is, the ferrous oxide phase) is formed with no visible change in microstructure, but after heating for an hour at this temperature, finely divided iron particles become visible (Figure 2). On heating for longer periods of time, the microscopic particles of iron coalesce to form large widely separated grains, (Figure 2) and these iron grains are quite resistant to the etching action of acid. Pfeil attributes these slow etching phenomena to the comparatively slow attack of the acid on FeO in the quenched sample in one case, and on the slow attack of the acid on the large grains of pure iron in the other. Upon annealing quenched FeO for a short time, submicroscopic particles of iron were precipitated throughout the Fe_3O_4 matrix; the rapid etching of the scale in this condition Pfeil attributed to the presence of the finely divided iron in contact with the Fe_3O_4. If Pfeil's findings are analyzed in the light of electrochemistry, some very interesting results are obtained. When an acid solution is brought into contact with iron covered with a normal scale, several electrolytic cells are possible, namely:

Electrochemical Cell	Voltage
(1) Fe/acid/FeO	0.415
(2) Fe/acid/Fe_3O_4	1.42
(3) Fe/acid/Fe_2O_3	1.18
(4) Fe_3O_4/acid/Fe_2O_3	0.47

From theoretical considerations [1], the free energy and the voltages of these electrochemical cells can be calculated at the standard state. In chemical reactions, the chemical change which has the greatest voltage is the most probable one to take place. Returning to the consideration of the decomposition of the FeO phase at 1,065 degrees F. (574 degrees C.), it can be seen that

FIGURE 2—Ferrous oxide passes through various phases upon being subjected to different time and temperature conditions.



FeO PHASE
QUENCHED

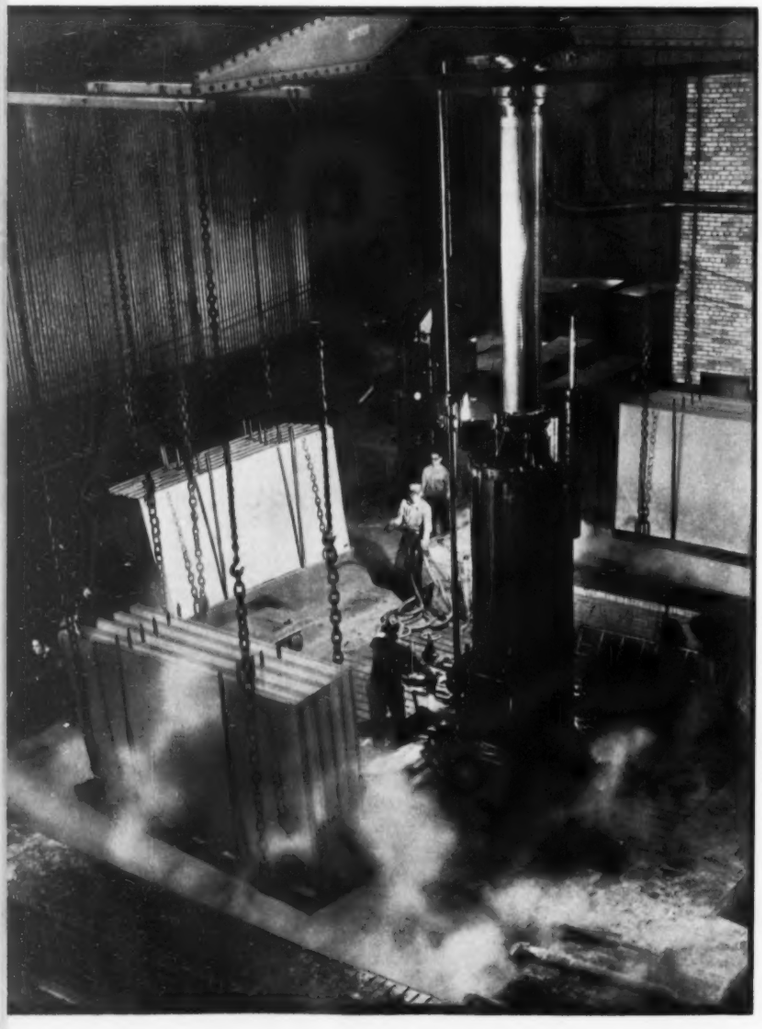
FeO PHASE
HEATED ONE HOUR

FeO PHASE
HEATED LONGER THAN ONE HOUR

the voltage is high for the reaction between Fe and Fe_3O_4. The resulting high electromotive force of this cell in an acid electrolyte shows that unless there are interfering conditions, this reaction would take place as indicated. With the finely divided iron precipitated in the Fe_3O_4 matrix by annealing, both the external and internal resistances of the Fe/acid/Fe_3O_4 cell are low and the possibility of a vigorous reaction is very good. When these particles coalesce on prolonged tempering at 1020 degrees F. (549 degrees C.), the iron particles become so large that the number of electrolytic cells is greatly diminished and the rate of solution in acid is consequently decreased.

This rapid solution in acid of the normally cooled ferrous phase is of great importance when it is understood that the most probable mechanism for pickling consists of the solution of this ferrous phase and the mechanical detachment of the remaining oxides from the base metal. It is quite probable that the difficulty in pickling box annealed steel is due in part to the coalescing of iron particles in the ferrous phase during the cooling portion of the annealing cycle. In like manner the comparatively rapid pickling of hot rolled strip may be attributed to the presence of finely divided iron in the Fe_3O_4 matrix of the ferrous phase.

FIGURE 3—Conventional type of batch pickler for use with sheets or strip in cut lengths.



The mechanism for the formation of scale, as presented by Pfeil is the countercurrent diffusion of oxygen from the surface of the scale and of iron from the surface of the base metal. Other workers investigating the oxidation of iron with other gases (CO_2 and steam) have verified Pfeil's theory, when it is modified to account for the diffusion of gases into and away from the scale.

By properly controlling the atmosphere of the heating furnaces it has been found possible to greatly reduce the scaling. When this smaller amount of scale has the proper composition, pickling may be carried out rapidly and economically. The controlled atmosphere should prevent the over-oxidation of the scale to the higher oxides, and should increase the proportion of the ferrous oxide layer, if rapid effective pickling is to be obtained.

In pickling, both hydrochloric and sulphuric acids are used. Because of its lower cost, the latter is almost universally preferred in this country. The chemical process for both batch and strip pickling are essentially the same. The pickling bath will usually consist of from 3 to 15 per cent acid, the iron content will vary from a very low value in a fresh tank to 20 to 25 per cent $FeSO_4$ (2.5 pounds/gallon) in an old tank, and the temperature from 150 degrees to 210 degrees F. Each of these variables are more or less interdependent and will be governed by the equipment used and product being pickled. Careful control of the chemical composition and temperature of the bath should be maintained, by methods and equipment which are well known. Agitation is also very important in the pickling process, in order that fresh acid may be brought to the surface being pickled, and the spent acid and and loosened scale removed.

It is generally believed that in pickling the acid penetrates the scale and dissolves the ferrous oxide phase or bond between the scale and base metal. This permits the scale to be lifted from the steel surface by the evolution of hydrogen and by the agitation of the pickle liquor. The acid also is dissolving the other parts of the scale. Because of the lower rate of solution of the other oxides, the scale is usually not completely dissolved but lifted off of the surface of the steel.

Inhibitors are usually used in the pickling bath to control the pickling process and prevent over pickling. The majority of the inhibitors [1] used commercially today are organic in nature and in an acid solution form positively charged colloids. These positively charged particles migrate to the negatively charged cathode areas, and are adsorbed at the surface of the steel. In this manner the discharge of hydrogen ions is inhibited by the blanketing of the steel surface. Since the iron is anodic to the scale, the inhibitor does not protect the steel surface until the scale has been removed. After the scale has been removed from an area of the steel surface, certain portions of the surface will be cathodic to other portions, due to composition, grain orientation, etc. The positively charged colloids are then absorbed by these cathodic areas, and the evolution of hydrogen is largely prevented. The use

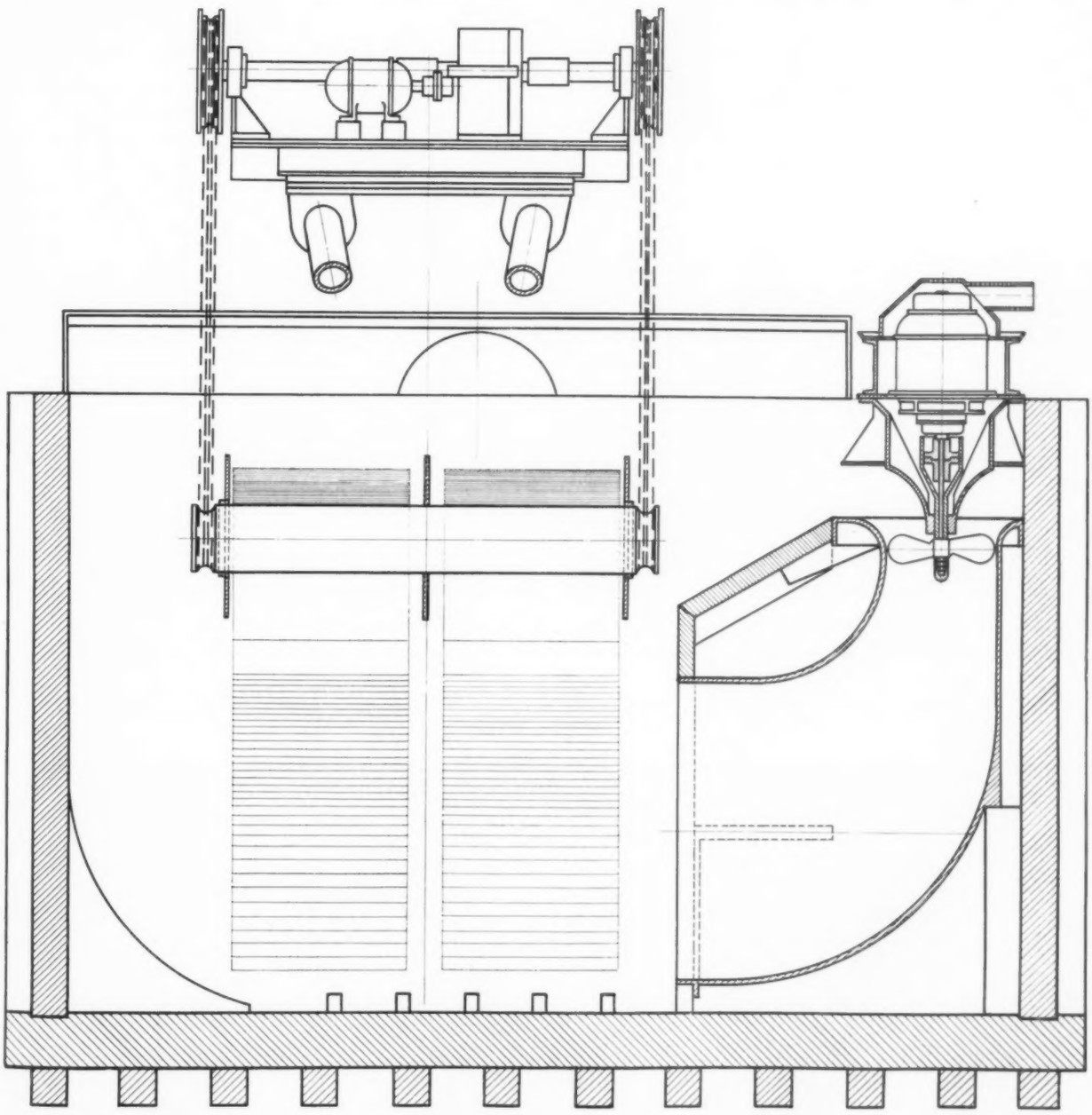
of inhibitors will assist in the prevention of over pickling, reduce the evolution of hydrogen and use of acid, and assist in controlling the pickling process. In this manner the formation of blisters and embrittlement due to hydrogen can be diminished.

When hot rolled strip, on which the scale has been broken, is pickled, a surface defect frequently called "alligator hide" or acid etch, results. The defect is the result of the rapid attack of acid on the bare steel before the remainder of the scale is removed. This attack is undoubtedly accentuated by the electrochemical reaction noted above. Inhibitors will not prevent this attack since the iron is anodic to the surrounding scale and the positive colloids are not absorbed at anodic areas.

It has been well known for some time that atomic hydrogen will diffuse through metal and that inhibitors will considerably reduce the amount of such hydrogen diffusing into the metal. For blisters to form in steel, voids or inclusions must exist in the metal. The atomic hydrogen diffusing through the metal comes to any discontinuity, such as an inclusion, and here accumulates forming molecular hydrogen. This molecular hydrogen cannot diffuse through the metal.

It is evident that the high pressures necessary to

FIGURE 4—Diagram showing method of acid circulation in rotary type batch pickler.



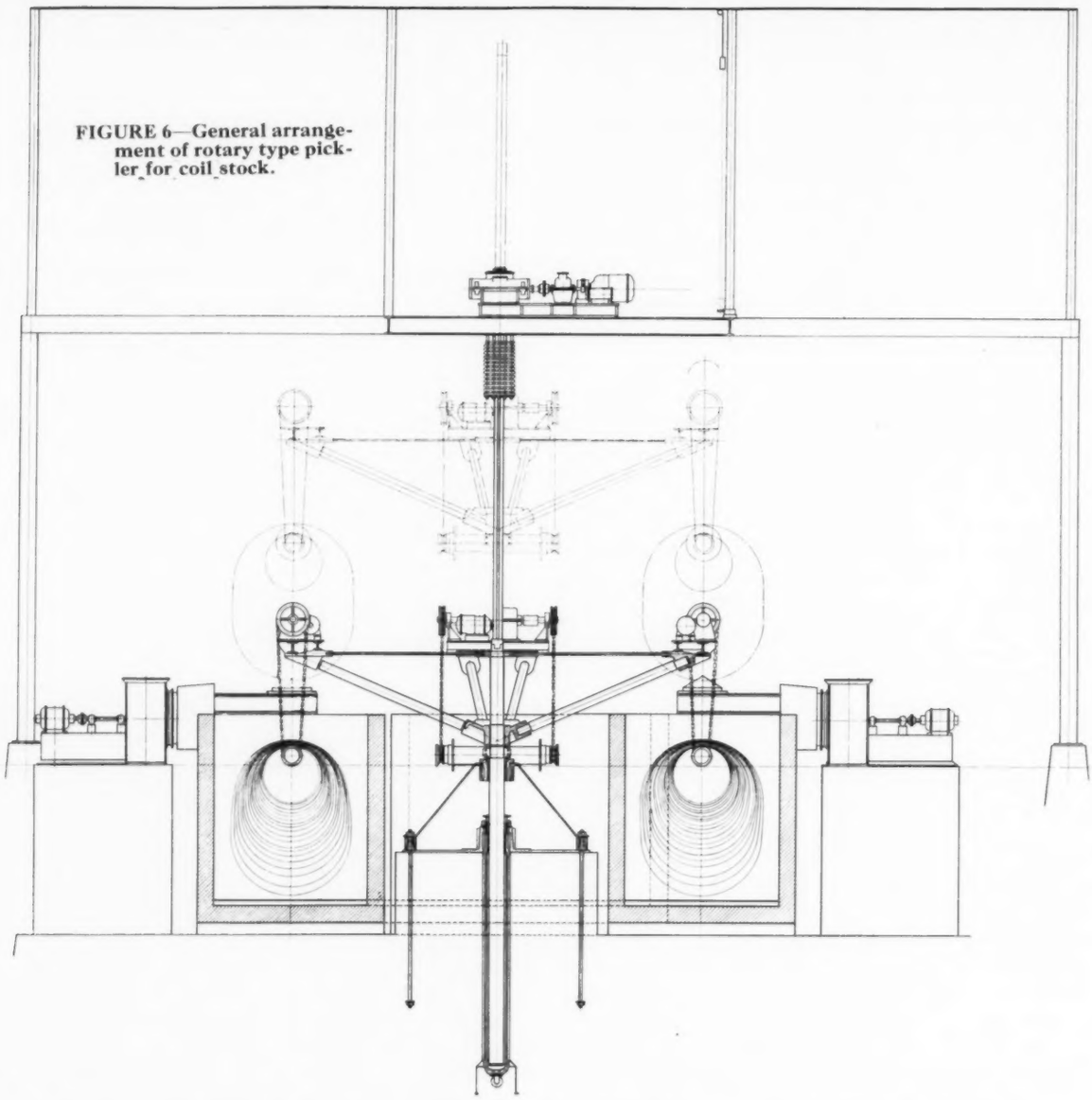


FIGURE 6—General arrangement of rotary type pickler for coil stock.

FIGURE 5—Loose wound coils are brought to the loading station on a gravity conveyor.

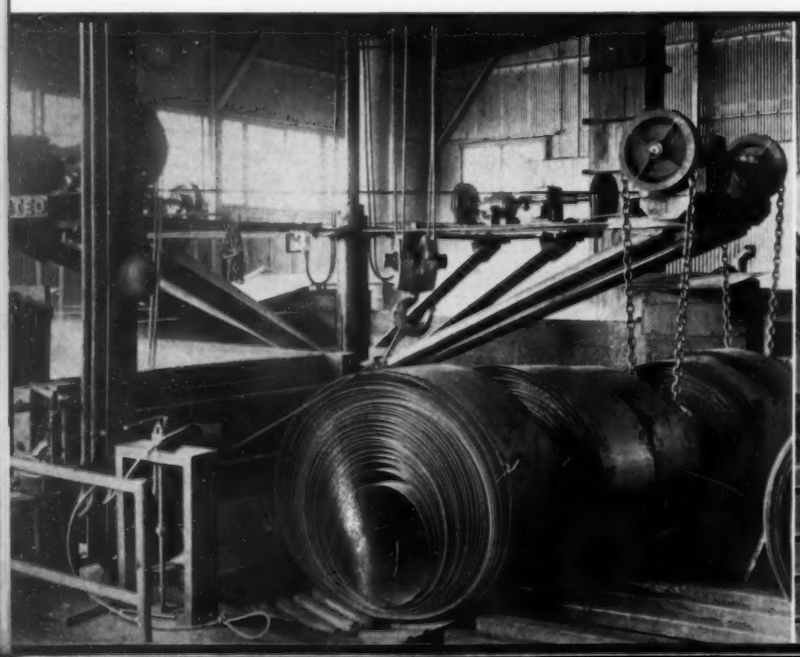
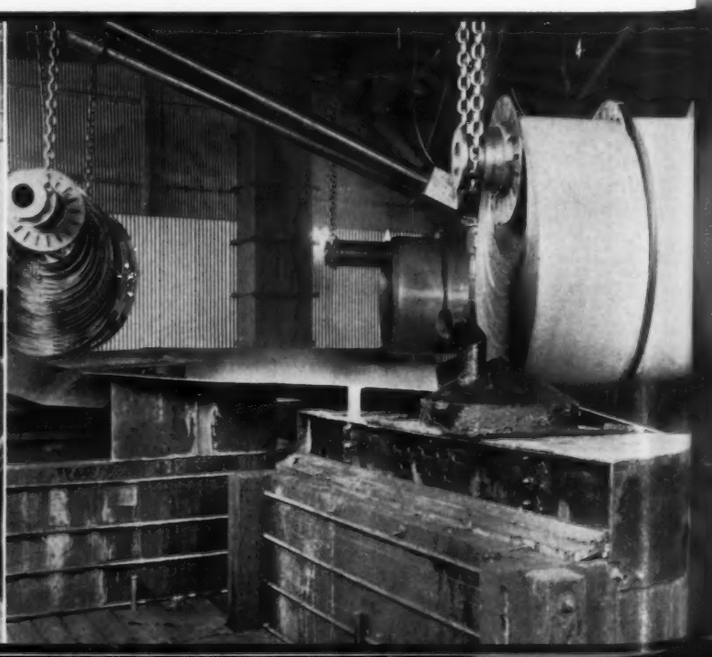


FIGURE 7—Coils are placed on mandrels which are rotated by a chain driven from above.



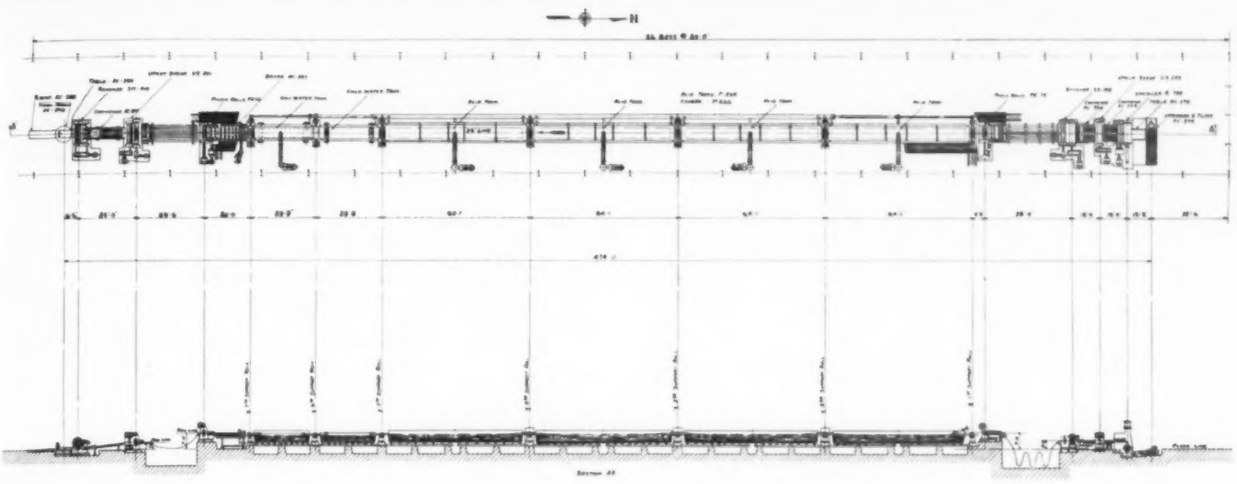


FIGURE 8—Diagram of modern continuous pickling equipment for coil stock, showing the various equipment units employed.

deform the metal in producing blisters are due to the hydrogen liberated during the pickling operation and diffusing into the surface of the steel. The pressure necessary for the formation of a bubble of hydrogen whose radius is 10^{-7} cm. has been calculated by Hayes [3] to be 21,000 psi. It is quite evident that the use of inhibitors which reduces the discharge of hydrogen ions will also reduce the formation of atomic hydrogen and will decrease the amount of hydrogen which is available for diffusion. For this reason inhibitors are very useful in the prevention of blisters.

In pickling sheets or strip in cut lengths, a batch pickler such as is shown in Fig. 3 is used. This process is very familiar and will not be described in detail.

The rolling of hot strip in wide widths on four high continuous mills was started in 1927. Soon customers were demanding coils of hot rolled pickled, and cold rolled steel in these widths. To meet these demands each company set about building a strip pickler to enable the manufacture of these products. The resulting equipment was not entirely satisfactory because mechanical equipment had not been developed to convey strip steel through the long baths necessary for pickling.

In recent years, a pickler known as a rotary coil pickler has been developed. In this rotary pickler, loose wound coils are rotated on a mandrel in the acid tank while the solution is circulated by a motor driven propeller, with a flow at right angles to the rotation of the coils. From Figure 4, it can be seen how the rapid circulation of acid through loose wound coils brings fresh acid to the scaled surface, and removes scale which has become detached from the steel.

In loose coiling a hot rolled coil, the ends are sheared square, and it is coiled tight on the loose coiler. After bring tightly coiled, the direction of rotation of the coil is reversed and loose coiling is accomplished by delaying the loose end of the coil by impact on one cradle roller in each revolution of the coil. The result is shown in Figure 5. The same loose coiling may be accomplished in a three roll bending machine in which one roll is controlled by a cam to secure a definite spacing of the coil. The loose wound coils may then be carried on a gravity conveyor to the loading station of the rotary pickler. (Figure 5.)

The rotary pickler has four stations: loading, pickling, rinsing in cold water, oiling in hot water-soluble oil solution. A general idea of the arrangement may be obtained from Figure 6. In loading, one or more coils are loaded on the mandrel. At the proper time in the cycle, the mast is lifted raising all of the coils and rotated through 90 degrees (Figure 7). As the mast is lowered the circulating motors are started and also the motors driving the chains which rotate the mandrels. In this manner the coil is alternately opened and closed due to its rotation on the mandrel. At the same time, the acid is being rapidly circulated through the open part of the coil. After a sufficient time has elapsed for complete pickling, usually five to ten minutes, the mast is lifted, rotated 90 degrees and lowered, the coil being immersed in the cold water rinse tank. After thorough rinsing, the coil is moved to the third position where it is immersed in a hot mixture of water, soluble oil and light machine oil. The coil is being rotated and the solution vigorously circulated in both cold rinse and hot-water-oiling treatment. On being drawn from the oiling solution, the water evaporates leaving the coil coated with a thin layer of oil. The coil is finally delivered to the loading station where the coil is unloaded and transferred to the storage for cold rolling or delivery to the customer. The raising of the mast during the changing from one station to the next is accomplished by introducing high pressure oil to the ram cylinder from a hydro-pneumatic accumulator and pumping system.

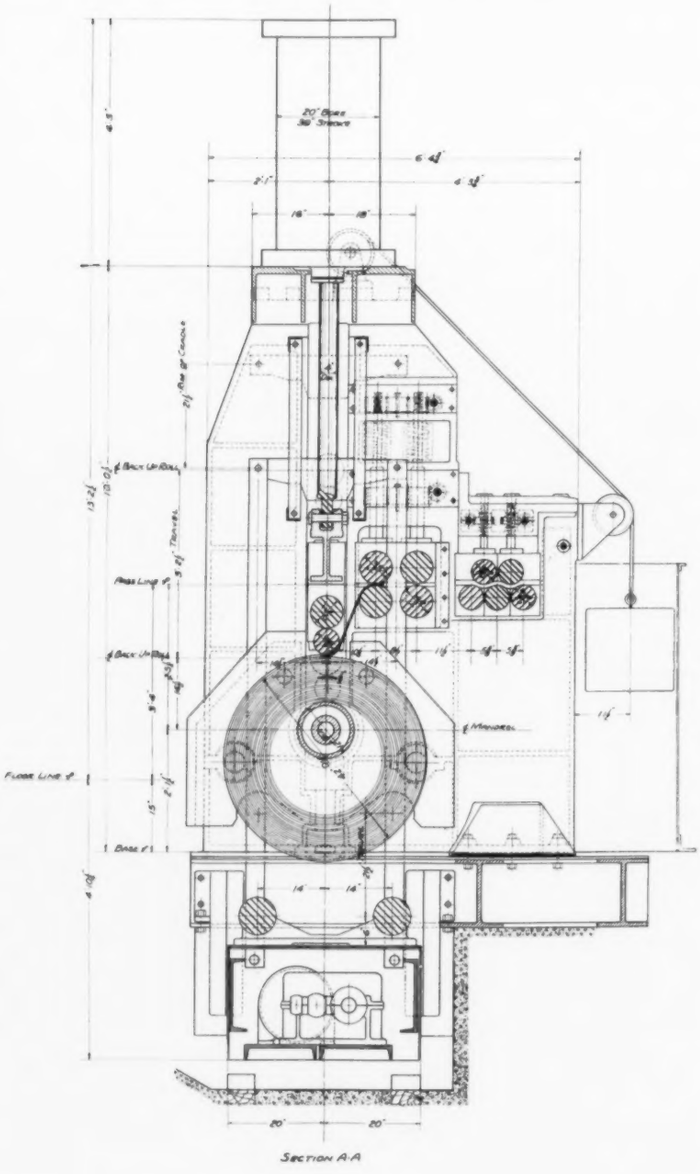
The principal advantages of the rotary pickler are low first cost, minimum requirement of space and equip-

(3) Hayes, Trans. Am. Soc. Steel Treating, *17*, 527 (1929).

ment, simplicity of operation and adaptability for handling coils of varied width and gauges.

The development of conveying equipment for strip picklers has been intensively studied and more recent designs are much more efficient than the earlier pickle lines. A modern strip pickler (Figure 8) will usually consist of an uncoiler, roller leveller, shear, stitcher or welder, looping pit, pinch rolls, pickling tanks, rinse tank, hot water tank, air dryer, pinch rolls, looping pit, shear and recoiler. Each of these operations is performed by a machine especially designed for the intended purpose. For the most part, these operations are well known and will not be discussed in detail. There are several operations which have been designed specifically for application to strip pickling lines and should be described in detail.

FIGURE 9—Cross-section of processing unit, showing travel of strip through the unit.



The coil to be pickled is first run through a processer or scale breaker. In this processer, the coil is mounted on a mandrel, and the strip is pulled under tension around a roll of small diameter maintained in position by a hydraulic cylinder and held under a constant pressure (Figure 9). By maintaining a uniform pressure on the coil between the small roll and mandrel, the coil is unwound under the same conditions throughout its length. When the strip passes around the small roll, a very large number of fine cross breaks will be formed. The strip is then bent in a reverse direction, around a roll of small diameter, where it enters a roller leveller. These fine cross breaks are so small and so close together that they are not objectionable. In addition the amount of cold work is sufficient to eliminate cross breaking in the remainder of the pickle line. The working of the scaled strip, loosens the bond between the scale and steel, which enables the acid to penetrate the scale more readily, increasing the rate of pickling. In addition, the roller leveller produces a flat strip.

After flattening, the ends of the coils are sheared square, the ends of coil overlapped and stitched together. In some installations the coil ends are welded together, forming longer coils for the cold strip mills than could otherwise be produced. Stitching is apparently the more foolproof method of joining coils, for pickling, especially in the lighter gauges.

After passing through the looping pit and pinch rolls, the strip is carried into the pickling tanks. In the past, many materials have been tried in the search for a satisfactory tank for pickling. Among these combinations have been various kinds of wooden tanks, concrete and lead lined, acid proof, brick tanks, lead lined steel tanks, and many others. The majority of the pickling tanks today are made of rubber lined steel. Within this lining are laid acid proof brick with an acid resistant cement. There are no holes in the bottom of the tanks and no stoppers nor valves to leak acid. The tanks are dumped by siphoning the spent pickle liquor out of the tank. Whenever these tanks are drained, they are carefully cleaned, and inspected, and any loose bricks removed and reset in cement. The rolls for the ends of the tanks are rubber covered and mounted on the outside of the tank. The strip dips under the acid solution by its own weight, eliminating the necessity of rolls or bearings being in the acid solution.

The tanks are mounted well above the floor line and any leakage from them can easily be detected. In an installation of this kind, consideration should be given to the separation of strong acid solution from the rinse water which is very low in acid content. A dual sewer system is frequently used so that these two solutions may be disposed of separately. This method of handling the high and low acid solutions will be very useful when it becomes necessary to dispose of pickle liquor by means other than by dumping.

In order to eliminate the vapor nuisance in the pickle house, the heated tanks are covered with rubber covered steel hoods. A slight negative pressure is maintained under the hoods and the vapors are pulled by fans into the exhaust system. Water sprays are set up

to wash the acid bearing mist out of the air, and the discharge from the exhaust system is comparatively free of acid.

The pickle liquor is agitated by steam jets which are used to maintain the temperature. The temperature is usually automatically controlled with a controller-recorder of the conventional type. The pickle liquor in such a strip pickler will ordinarily be maintained with an acid concentration of 8 to 12 per cent and at a temperature of 175 degrees to 200 degrees F. An inhibitor is usually used in the pickling acid.

After pickling, the strip is run through an overflowing cold water rinse, a hot water rinse, an air blast for drying, and pinch rolls for pulling the strip through the pickle line. The dried strip passes through a looping pit, a shear where the stitching or welding is sheared out, and the coil is finally recoiled. It is customary to oil the pickled strip just before or during the coiling operation. A mirror and lights are conveniently located to inspect the under side of the strip before oiling.

The speed of the strip through the pickling tanks is ordinarily controlled by a Ward Leonard system of control in conjunction with a dancing roll at the front end of the first tank. The dancing roll controls the depth of the strip in the acid. When the strip is too high or too low, the dancing roll actuates limit switches which accelerate or decelerate the pinch rolls, permitting the strip to be lower or higher in the pickle tank. A set of lights indicates whether the strip is above or below its normal position. During a break down, the strip may be pulled out of the acid by the pinch rolls, in order to prevent over pickling. The units at each end of the pickle line are independently controlled in order to eliminate unnecessary delay in joining the coils at the entrance end, or recoiling at the exit end.

In summarizing the advantages of the modern strip pickler over the earlier pickler, the following points should be enumerated:

(1) Development of processer to uncoil hot roll strip without objectionable cross breaks.
(2) More rapid and uniform pickling due to the working of the steel-scale bond.
(3) Stitching of coils instead of welding.
(4) Use of looping pits to eliminate unnecessary delays.
(5) Rubber and brick lined steel tanks instead of

FIGURE 10—Entry end of strip pickler showing processor in the foreground, with looping pits and tanks in the background.

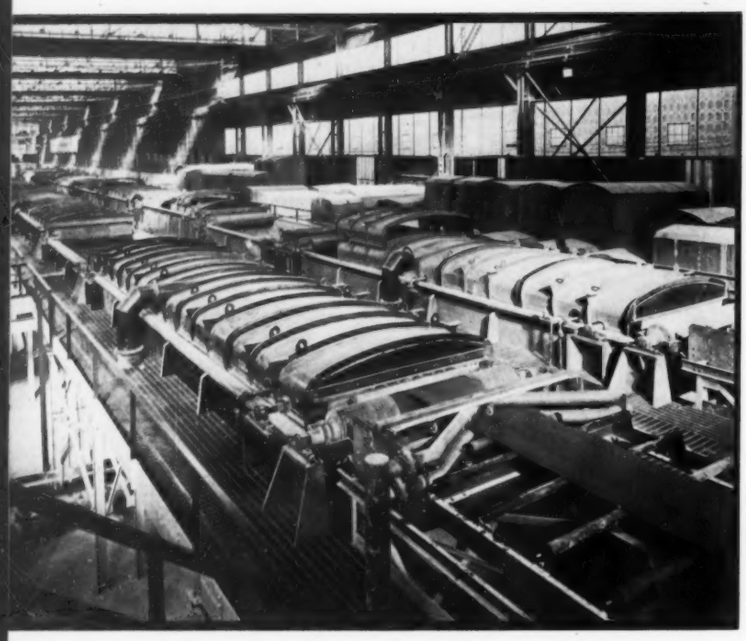


FIGURE 11—Exit end of strip pickler showing cold and hot water rinse tanks followed by drying equipment.

wooden tanks, with no holes in the bottom of the modern tanks.

(6) Rubber coated steel hoods to remove fumes, and water spray to remove acid droplets from exhaust vapors.

(7) No rolls nor bearings in the acid solution; both of which were used in the original design.

(8) Tanks above floor line, making leakage easily detected compared with tanks usually located below floor level.

(9) Dual sewer system for separating strong acid and weak acid, whereas, formerly all acid and other waste products were dumped into the same sewer.

(10) Ward Leonard system for controlling speed and tension, and automatic temperature control for the acid.

Several views of various pickling lines embodying these operations are shown in Figures 10 to 12. These pictures include the strip pickling lines in the Cleveland plant of the Republic Steel Corporation.

In presenting the metallurgical viewpoint of the pickling process, an attempt has been made to assemble information bearing on this subject from the various scientific fields, chemistry and electrochemistry, as well as metallurgy. It is hoped that the data from these various fields will clarify the problems which arise in the pickling of strip steel.

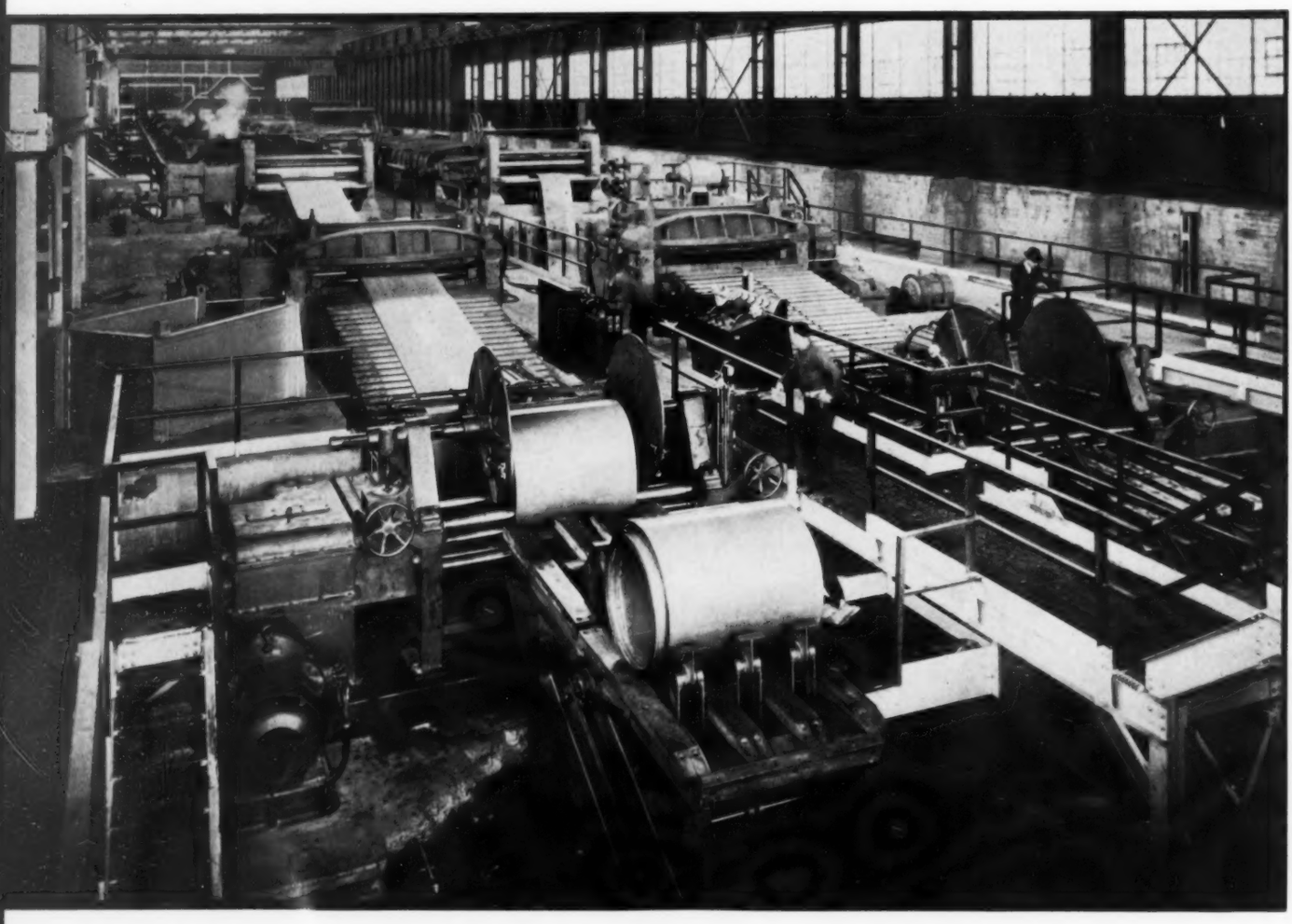


FIGURE 12—At the end of the pickling line, strip is separated by shearing and passes on to the recoiler.

DISCUSSION

PRESENTED BY

C. L. McGRANAHAN, Assistant General Superintendent, Jones and Laughlin Steel Corporation, Pittsburgh, Pennsylvania.

H. P. MUNGER, Metallurgist, Republic Steel Corporation, Warren, Ohio.

C. L. McGRANAHAN: The majority of the modern broad strip mills are equipped with a hot flying shear adjacent to No. 10 stand, and the product is piled at the end of a run-out table on a hot piler. The centers of the pile, being in more or less intimate contact, are annealed and the oxide reduced due to the high finishing temperature possible on such a mill. The result is that the sheet carries a heavy blue border and a reduced oxide in the middle. Have you encountered any difficulty in getting a white sheet on this product in the heavy gauges? We have encountered some difficulty at Jones and Laughlin.

H. P. MUNGER: In our experience we haven't run into that particular problem since, at Niles and at Cleveland, we are pickling coils rather than cut lengths. I have never run into this particular trouble, but I can appreciate how difficult it would be.

C. L. McGRANAHAN: I have another question, Mr. Munger. Have you encountered any difficulty in continuous pickling of the light gauge narrow strip —that is, especially with regard to removing the scale along the edges—such as 16 gauge or 14 gauge for tin plate?

H. P. MUNGER: We have never encountered such difficulty. One of the ways of eliminating it would be to increase the activity of the pickling tanks by decreasing the speed or increasing the temperature or acid concentration. Overpickling of the centers of the strips could be prevented by the addition of inhibitors. The majority of the scale would be removed from the center before the strip had been in the acid a sufficient length of time to give the pickle etching which is found when strip with broken scale is pickled.

WALTON DISCUSSION

(*Continued from page 49*)

built by three different large electrical manufacturers and were in three different localities.

For the protection of direct current machines, we also use capacitors. If there is a steep wave front voltage, trouble may occur, such as spilling across between commutator bars or between turns. In one case, a surge voltage of 10,000 volts was measured across the armatures of two 1500 volt d-c. generators in series, due to the sudden cutting off of 1 ampere through the reactance of the machine. This was cured by putting a condenser across the terminals. That happened to be in a broadcasting station that was occasionally shut down by this trouble. So you can use capacitors for the protection of direct current equipment.

One gentleman spoke about the "last wham". That, apparently, is the matter of progressive failure that I spoke of. You may get by the lightning storm, and then when the motor has been running for a while, it may fail afterwards. The insulation was just about ready to fail and it didn't take much to spill it over.

There is a great deal of energy in an arcing ground. I do not believe that any lightning arrester manufacturer will guarantee against failure due to arcing grounds. If there is a large amount of energy dissipated in a lightning arrester, and it continues for a long enough time, the thermal capacity of the device will be exceeded.

You men are all interested in keeping your plants in operation and holding down the maintenance cost. If you will take the trouble, when a motor fails, to examine it to see whether the failure is outside of the iron, whether it could have been a turn to turn failure, whether it is near the neutral, or halfway between the terminals of a delta connected machine, and whether there are other places of incipient failure, I believe you will get very valuable information for the application of this type of protective equipment.

N. R. COX: I would like to ask one more question in regard to that lead cable. On a-c., in some cases lead cable has been installed in conduit; in other cases they have used a steel wire sheath lead cable. Would you expect to get any benefit directly from either the conduit or the steel wire sheath on that five hundred feet of cable the gentleman mentioned?

P. J. WALTON: The same answer applies, that is, a short length of cable does not give any real protection.

N. R. COX: Would you expect any addition to that with the conduit?

P. J. WALTON: If you have a lead covered cable with the lead sheath thoroughly grounded, and tied in at both ends with the lightning arrester ground and the machine frame, you will have a better grounding condition, but you do not get very much benefit from the capacity of the cable. If the cable does not have a lead sheath and merely has a steel protective band wrapped around it, it does not provide a good capacity effect anyway.

J. C. REED: I would like to ask one very pertinent question, and that is are coils useful or not?

P. J. WALTON: Years ago choke coils were installed but that was before very much was known about lightning. Since then, instruments have become available which have enabled us to learn the characteristics of lightning voltages, and we have been able to measure surge voltages. It has been found that we can get a higher voltage if a choke coil is installed, than if the choke coil is left out.

J. C. REED: I am still not sure whether to leave them in or take them out.

P. J. WALTON: I would recommend taking the choke coils out, or short circuiting them.

HISTORY *of* THE *Birmingham* SECTION

ASSOCIATION OF IRON AND STEEL ENGINEERS

By W. W. GARRETT, Engineer of Tests

Tennessee Coal, Iron & Railroad Co.

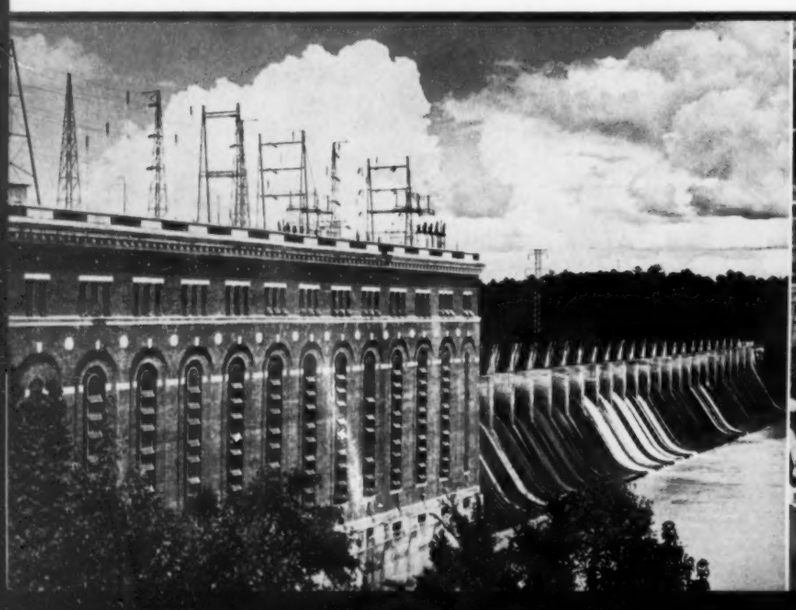
FAIRFIELD, ALABAMA

The history of the Birmingham Section is very apropos at this time in view of the fact that they are to act as hosts to the organization in Birmingham on March 27 and 28 at the time of the Annual Spring Conference.

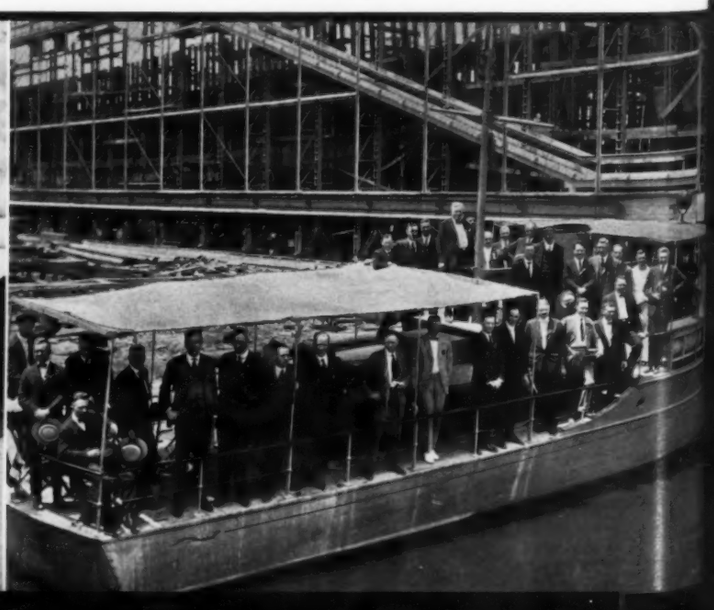
▲ FEW cities could offer such a background for the activities of the Association of Iron and Steel Engineers as Birmingham. It is located at the southern end of the Appalachian Mountains in a beautiful valley, blessed with every natural advantage. In the valley's center is the trading area with its skyscrapers rearing themselves far above wide and well laid streets. In the outlying districts are furnaces and steel mills, nightly lighting the sky with the glow of molten iron. On the mountains surrounding the valley are the homes of a happy and prosperous people who know the joy of nature's flowered hillsides and beautiful homesteads where southern hospitality reigns supreme.

Birmingham is called "The Magic City" because of the amazing rapidity of its growth. It seems almost incredible that in the short period of sixty-seven years any city could have grown to such size and to such influence. But when one knows that the pioneers of this city built upon the substantial foundation of coal, iron ore and limestone, all found together in abundance in the same valley, there is no longer cause to wonder. Upon such a foundation Birmingham has grown until today 13,500,000 tons of coal are mined annually in this district, 3,650,000 tons of coke are produced, as well as 2,500,000 tons of iron, and 1,770,000 tons of steel, together with a wealth of finished manufactured products.

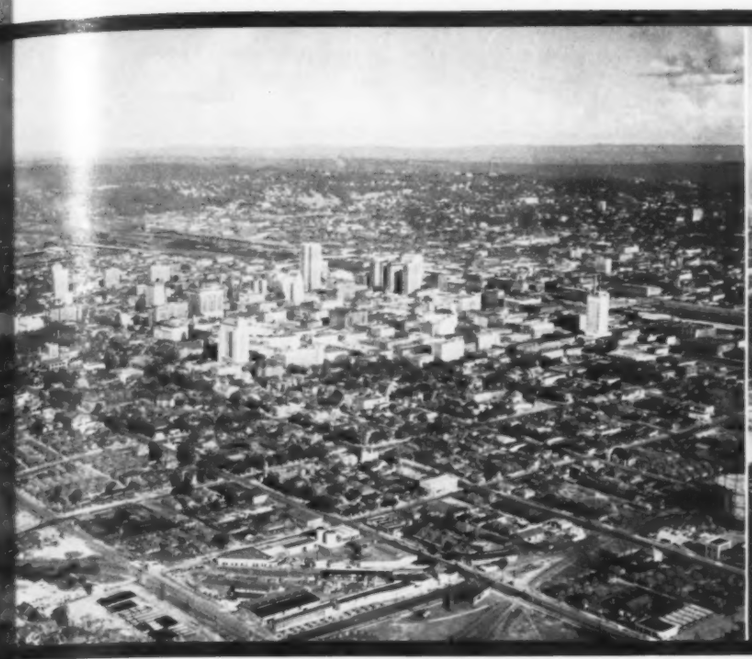
Birmingham has a metropolitan population of over 290,000. In size it is the thirty-fourth city of the United States. It is situated in the heart of the State of Alabama, which ranks first among the states in the deposits of crystaline graphite; second in the production of yellow pine; third in the production of iron ore; fourth in the production of marble; fifth in the produc-



Lock twelve (Mitchell Dam) hydraulic electric generating station of the Alabama Power Company on the Coosa River. This was the scene of the first inspection trip of the Birmingham section.



This group of Birmingham members made the inspection trip to the Chickasaw shipbuilding plant of the Tennessee Coal, Iron & Railroad Company near Mobile, Alabama, in 1921.



Aerial view of the City of Birmingham, where on March 27 and 28 the Association of Iron and Steel Engineers will convene for their annual spring conference.

Members and guests of the Association will inspect the recently completed tin plate project of the Tennessee Coal, Iron & Railroad Company at Fairfield, Alabama, Tuesday, March, 28.

tion of coke; fifth in the development of water power; sixth in the production of lime; sixth in the production of pig iron; seventh in the production of coal; ninth in the production of fire clay; and eleventh in the production of cement.

Alabama contains the second greatest iron ore deposits in the United States, and ranks first in the world in the production of cast iron pipe. The recent addition of finished steel manufacturing units in Birmingham has added greatly to the industrial importance of this city. Besides the bordering coal and ore fields, Birmingham is a railroad center connected with her customers on the north, east and west by nine trunk railway lines. Adequate highway and air transportation is also provided. On the southern border Birmingham has a water transportation system that leads directly to the Gulf of Mexico, and thence to the markets of the world. To such a city as this came the representatives of the Association of Iron and Steel Engineers to found its southern branch now known as the Birmingham section.

ORGANIZATION OF THE BIRMINGHAM SECTION

On March 27, 1919, in the twelfth year of the National Association of Iron and Steel Electrical Engineers, three men came to Birmingham for the purpose

The plant of the Goodyear Tire & Rubber Company, located at Gadsden, Alabama, was inspected by this group of some thirty-five members of the Birminhham District Section, in 1930.

The 1938 annual outing of the Birmingham group was held at the Cohaba River camp home of Jesse Jones with about 100 members and guests in attendance.

PAST CHAIRMEN - BIRMINGHAM SECTION

J. E. FRIES
1919-20-21

A. F. ELLIOTT
1922

A. L. FRERET
1923

W. B. CONNALLY
1924

F. G. CUTLER
1925

J. E. HARRELL
1926

W. W. GARRETT
1927

J. E. SAYER
1928

E. P. WINTERS
1929 and 1934

PAST CHAIRMEN - BIRMINGHAM SECTION

E. C. WINFIELD
1930

BIRGER THELE
1931

W. H. GILBERT
1932

W. J. DONAHUE
1933

C. R. TINSLEY
1935

J. B. LOONEY
1936

W. V. DUNN
1937

R. R. THOMAS
1938

F. M. STURGESS
1939

of organizing a local section. A. H. "Pop" Swartz was the leader of the group. He was accompanied by C. A. Menk, a past President of the Association and John F. Kelly, Secretary. These three representatives visited George Gordon Crawford, President of the Tennessee Coal, Iron and Railroad Company, and James Bowron, Chairman of the Board of the Gulf States Steel Company. The idea of these calls was to interest industrial leaders in the organization of the Birmingham Section and both of these men agreed to give their wholehearted support to the project.

The Birmingham Section was officially organized on March 29, 1919, at a Saturday night dinner meeting at the Tutwiler Hotel. The success of this meeting was largely due to the efforts of J. E. Fries, chief electrical engineer of the Tennessee Coal, Iron and Railroad Company and he was ably assisted by a group of local engineers, including R. H. Moore, J. H. Adkins, P. E. Davidson, F. D. Mahoney, Karl Landgrebe, W. C. Suppler, W. R. Yorkey, H. W. Matthews, R. T. Brooke, B. A. Schroder, and N. P. Farrar. Mr. Menk opened the meeting and appointed J. E. Fries as temporary chairman. Other engineers who were already members of the Association, and who were present at the organization meeting were A. L. Freret, F. M. Sturgess, R. H. Moore, Joe Thomas, and W. H. Gilbert. These men were declared to be charter members of the Birmingham Section. About forty engineers attended the organization meeting and all of them were given the opportunity to make application for membership in the Association. Those whose applications were approved by the local as well as the national directors for active membership were as follows: O. B. Allgood, A. N. Avera, W. B. Connally, W. J. Donnahue, W. V. Dunn, A. F. Elliott, W. W. Garrett, W. J. Wilson, R. B. Gordon, J. E. Harrell, J. L. Mason, J. E. Sayer, Joe Thomas, W. C. Suppler, H. T. White, and E. P. Winters. The names of engineers whose applications for associate membership were approved were as follows: E. B. Brooke, R. T. Brooke, C. W. Burney, J. J. Greagan, W. H. Price, B. A. Schroder, C. P. Yanch, W. R. Yorkey, and J. H. Adkins.

The first regular meeting was held on Saturday night April 26, 1919, at the Tutwiler Hotel. The first business was the election of officers for the local section. The following men were nominated by a previously appointed nominating committee and all the nominees were unanimously elected: J. E. Fries, chairman; W. H. Gilbert, vice-chairman; F. M. Sturgess, secretary; and J. H. Adkins and R. H. Moore as assistant secretaries. Two very interesting papers were presented at this meeting. W. C. Suppler spoke on "Electrical Department Organization", and E. B. Brooke gave a very instructive talk on "Wireless Telegraphy in Connection with Power Distribution in the Birmingham District". The special guests attending this meeting were D. M. Petty, president of the Association; John F. Kelly, secretary; the always welcome A. H. "Pop" Swartz; and T. J. Fleischer.

By the time the second regular meeting of the section on the last Saturday in May, forty members had been received into the local group. At this meeting definite plans were made for an outing to be held on July 4th. A paper on "Standardization of Test Reports" was given by W. W. Garrett.

The third meeting was in the form of a trip to the Lock Twelve (Mitchell Dam) hydraulic electric generating station of the Alabama Power Company, on the Coosa River. This was the largest generating plant in the state of Alabama at that time. Members took the train for Calera, where they were met by five automobiles and conveyed over some very rough roads to the dam. It was deemed wise to charter a wrecker to go along with the party to take care of tire and other troubles that might develop. It rained hard, the roads were slick, and the wrecker was used a-plenty. A very profitable day was spent at the plant, a fine dinner was served and the trip was voted a very successful event. During the summer months the Executive Committee made plans for the next season's program. J. E. Fries and J. H. Adkins represented the section at the thirteenth Annual Convention held in the city of St. Louis.

For the next two years, the section re-elected the same group of officers. During this period interesting papers were read before the section, dealing with the district manufacturing plants and with problems of particular interest to the local section.

Following this, section officers were rotated each year. Photographs of the chairman are included in connection with this history. Each year a technical program was presented, covering a wide variety of subjects, and inspection trips were scheduled periodically. Although difficulties of various nature were encountered at times, the pioneers of this section worked diligently and aided by several good friends in the district and by the Association headquarters, the Birmingham section succeeded in carrying on their program of activities through the lean years, with prospects for the future.

In 1936 the Birmingham members voted, as did the other sections of the Association, to change the name to the Association of Iron and Steel Engineers, in recognition of the broadened field of activities. Since this time, sectional interest has increased and membership has grown materially. It is anticipated that the recent plant expansion in the Birmingham district will further increase the section's membership, and that the broadened activity and closer cooperation of Association headquarters will lead to renewed growth and vigor.

In 1938 the section received a grant of $1000 from the Association headquarters, to be used in the district in furthering the Association's educational program. The local committee recommended two $500 graduate scholarships. One of these is now in progress at Alabama Polytechnic Institute, the other at University of Alabama.

The Birmingham section is honored to act as host to the Spring Conference of the Association, and looks forward to greeting many old and new friends at that time.

THREE-HIGH BALANCED MILL LOWERS PRODUCTION COSTS

▲ To compete with the modern continuous hot strip mills, steel plants using the conventional two-high hand sheet mills are constantly faced with the problems of reducing costs of finished sheets and improving rolling methods.

With this situation becoming more acute, Continental Roll and Steel Foundry Company began the development of a mechanical unit which would be adaptable to the existing mill drive and local plant conditions, and which would produce far greater tonnage with considerably less man power, at very low initial investment compared to the continuous strip mill installation.

As a result of this pioneering, the mechanized sheet mill today is an extremely versatile, high-production, low cost unit, consisting of a three-high balanced roughing mill and two or three two-high mechanized finishing mills.

For rolling sheet bar $\frac{9}{16}$″ thick and under, a three-high jump mill is used for roughing. The new three-high balanced mill is recommended for rolling sheet bar from $\frac{5}{8}$″ to 2″ in thickness. Both mills are designed to produce an average of 1800 pairs of sheet bars per eight hour turn, based on operation of five passes per pair, consisting of two single passes and three matching passes. While tonnage figures vary according to the difference in size of sheet bars, the average tonnage of the three-high balanced mill is about 90 tons for eight hours, while that of the jump mill is about 60 tons.

Three-high balanced mills usually have top and bottom rolls 32″ in diameter, and a middle roll of 20″ in diameter. While it is possible to roll wide widths of sheets on a mill of this type, most automatic sheet mill units have been designed for rolling sheets up to 48″ finished width. Size of sheet bar varies from 8″ to 16″ in width, and of length suitable for producing desired width of finished sheet usually from 26″ to 52″.

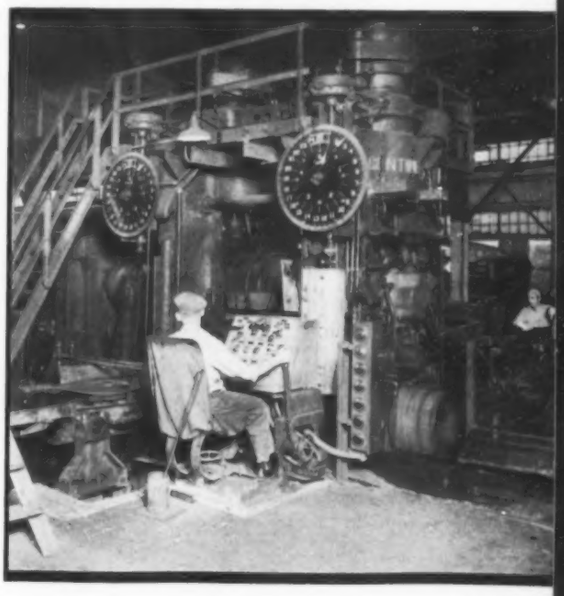
The three-high jump mill is the simpler of the two units, and is preferable when rolling sheet bar less than $\frac{5}{8}$″ thick. This type of mill is usually equipped with a hand-operated screw-down, consisting of spanner wheels and wrenches. The bottom roll only is driven, and the middle roll and top rolls are idle, and depend for their rotation on friction between the middle and bottom rolls.

The top and bottom rolls are fitted with fabric bearings supplied with water sprays. The top roll is arranged with suitable wipers to keep the water from coming in contact with the hot material. To provide an ample supply of water for these water bearings, bronze water manifolds are furnished and so arranged that they may be readily removed and replaced with clean manifolds without disturbing the operation of the mill. On the other hand, the middle roll is mounted on roller bearings securely sealed against water and scale, and enclosed in cast steel chocks.

To insure flat rolling of the sheets, the middle roll is provided with lateral adjustment, so that its axis may be placed slightly ahead of the top and bottom rolls if desired. Large clamps are provided to hold the chocks firmly in position, and to avoid breakage of clamp bolts. These clamps are slideably mounted on machined surfaces, so that they may be readily moved out of position when changing rolls. The complete roll change of the middle roll can be made in less than five minutes.

The mill and tables are supplied with an automatic pressure lubricating system for all lubrication points. All grease and water piping is sup-

The three-high balanced mill is capable of rolling sheet bar from $\frac{5}{8}$″ to 2″ in thickness. The average tonnage of this mill is about 90 tons for eight hours.



plied with the mill up to the point of connection to the main supply.

The three-high roughing mill embodies all of the latest mechanical and electrical features known to the steel industry, and it is a far cry from the old style hand sheet mill.

The motor-driven screwdown is designed with an extremely low inertia factor, provided for quick stopping and starting of the screwdown-mechanism to permit speed and accuracy in pass setting. The screwdown is of the worm and worm wheel type, totally enclosed and supplied with force feed oil lubrication to all parts.

The top roll suspension is effected by means of totally enclosed springs mounted over each screwdown mechanism, which are adjusted and locked in position when the mill is erected, eliminating the necessity of constant adjustment, such as is common on other types of three-high mills, in addition to eliminating the necessity of any cross member extending through the housing above the roll.

The middle roll is raised and lowered by means of stilliard rods connected through levers to pneumatic cylinders. These cylinders are operated by valves actuated by the motion of the delivery table, so that the middle roll must always be in its proper position with relation to the top and bottom rolls before the table is in position for entry of the bar into the mill.

This arrangement permits extremely fast operation of the middle roll balance mechanism, and insures against roll breakage caused by entry of the bar into the mill before the middle roll is in position to be backed up by either top or bottom rolls, as the case may be.

In rolling sheet bar on a three-high mill on which the top roll is driven, it is necessary to allow for a variable amount of slippage in the top roll to permit rolling of flat sheets. This slippage was usually obtained by means of a slip coupling mounted in the top spindle and adjusted by means of bolts and springs located at the periphery of the coupling.

In order to obtain the correct amount of slippage, the mill as well as the entire mill train had to be stopped and adjustment made, which, at best, was only an approximation, inasmuch as the correct effect of this adjustment could not be ascertained until the mill was again started up.

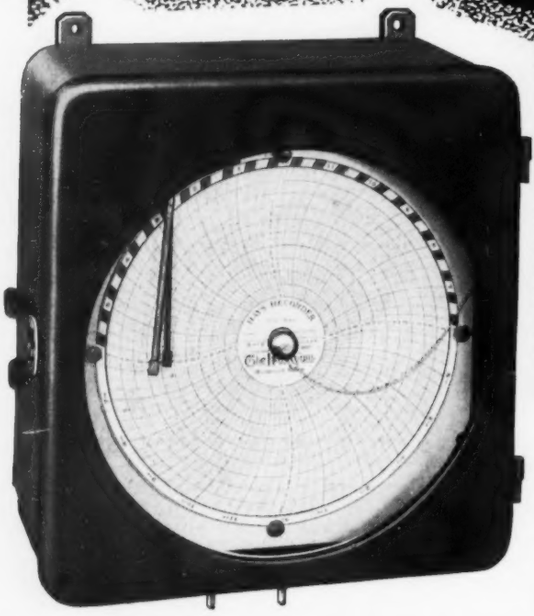
Here again, engineers have stepped to the foreground in developing a mechanism which permits the variable slippage of the top roll, and which can be adjusted from the outside of the pinion housing while the mill is in actual operation. This mechanism consists of suitable friction discs located in the top or middle pinion, and is totally enclosed in the pinion housing.

The pinion stand is designed with double helical cut tooth pinions, having an unusually large face, and with babbitt bearings of very liberal proportions. The bearings and the pinion teeth are lubricated by centralized pressure lubrication system.

While three-high mills have been designed for extremely high speed and accuracy of gauge, it was also necessary to have feeder and catcher tables of such design that they would be suitable for the rapid reversal, both in transverse motion and vertical motion, and yet to be built to

Super-Sensitive

THE HAYS "OT" DRAFT RECORDER



For Soaking Pits, Annealing Furnaces, Open Hearth Furnaces, Slab Mills, Dry Kilns, Filters . . . wherever an accurate record of draft pressure or differential is desired

GOOD STEEL PRACTICE today demands very accurate control of furnace operation.

Here the HAYS Series "OT" Supersensitive Draft Recorders perform an invaluable service by providing that knowledge of furnace conditions so essential to control.

These HAYS instruments accurately record draft, pressure or differentials of air or gases in ranges from .1 inch water to 100 inch water (total range).

Instrument cases are of either cast iron or aluminum—to resist corrosion in different atmospheres. HAYS "OT" Recorders are built husky enough to withstand dirt-laden air and severe operating conditions yet sensitive enough to register accurately increments of .0025 of an inch water. They are built to meet your particular operating requirements. Write to 955 Eighth Avenue, Michigan City, Indiana, for more detailed information.

The HAYS CORPORATION

SINCE 1901 COMBUSTION INSTRUMENTS AND CONTROL MICHIGAN CITY, INDIANA, U.S.A

eliminate all excess weight. And again, with an extremely fast operating mill unit and with quick acting tables, provisions must be made to permit the operators of such a unit to be comfortably seated, and so located that they may see quickly every operation of the mill. The engineers have missed no detail in design of the three-high mill and tables, which will make for easy operation and speed for obtaining maximum tonnage possible from a unit of this type.

Both the operator of the feeder table and the operator of the catcher table are conveniently located and seated on spring-cushioned chairs with the electric control box directly in front of them, and with hand levers and foot pedals for operating the raising and lowering of the tables and the raising and lowering of the various stops directly at their finger tips.

UNIT CONTROLS CHARGING OF STORAGE BATTERIES

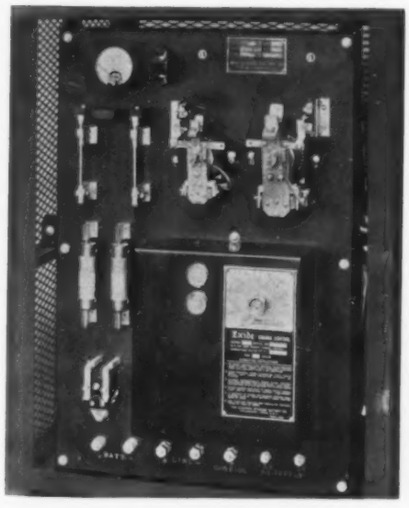
▲ The use of storage batteries in stationary service has grown tremendously in recent years. In many cases, due to temperature changes or to frequent demands, or to other uncontrollable causes, batteries cannot be kept fully charged without a considerable amount of manual supervision and maintenance.

Realizing that a need existed for a device that would automatically control the amount of charge given such batteries, the Electric Storage Battery Company set about the task of developing a practical unit that would keep the batteries fully charged with minimum supervision, and at very little expense. After three years of development work, this company has just placed upon the market the charge control Model ES, designed for use with any of the following charging systems, either bulb or dry disc types of rectifiers; d-c. generators, or d-c. bus with charging resistors.

In appearance, the new charge control resembles a metal case or cabinet, 11⅛" high by 10⅞" wide by 4½" deep with a hinged door. Within the cabinet a small, self-starting, synchronous motor-driven interval time switch, operating from a 60-cycle, a-c. supply, starts the charge or increases it once every hour by resetting a temperature compensated relay which, in turn, operates an auxiliary relay.

As soon as the battery voltage rises

The new charge control unit which resembles a cabinet, was designed to keep stationary batteries fully charged with minimum supervision.



CLEVELAND CRANES

ALL WELDED

Girders • End Trucks • Trolley Frame • Cage
All one piece Rolled Steel Units

• A Cleveland Steel Mill type Crane—15 ton capacity—63′ 6″ Span—operating over a Pickler Line in a Sheet Strip Mill.

• Cleveland Cranes give strength and rigidity without excess weight required for that continuous 24 hour performance.

ALSO BUILDERS OF CLEVELAND TRAMRAIL MATERIALS HANDLING EQUIPMENT

CLEVELAND CRANES

THE CLEVELAND CRANE & ENGINEERING CO.
1131 Depot St.
WICKLIFFE, OHIO.

NEW YORK DETROIT PITTSBURGH CHICAGO

to the temperature compensated relay operating voltage, the contacts of the latter open, de-energizing the auxiliary relay, which opens its contacts to stop the charge. A continuous-charge toggle switch is also provided in case it should be desired to temporarily discontinue the automatic charging feature. Not only does the new control greatly reduce the amount of manual supervision required, but it assures increased battery life and greater economy of charging current.

ACCURACY INCREASED BY NEW ARC WELDER

▲ A line of "shield-arc" welders, said to provide greater convenience and accuracy because of a new self-indicating dual continuous control, is announced by the Lincoln Electric Company, Cleveland, Ohio.

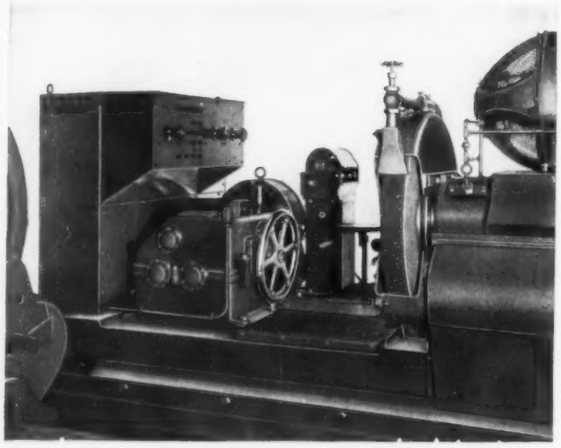
These welders have both job selector and current control calibrated and equipped with dials which indicate the type of work and the number of amperes for each and every setting. It is claimed that this development enables the welding operator to secure highest quality welds and highest possible welding speeds because he can vary both the slope of the volt-ampere curve and the amount of welding current independently and positively to suit every job encountered.

Another feature of this welder control is that both voltage control (job selector) and current control are continuous in operation. This design provides literally thousands of possible combinations of voltage and current. It is claimed that this simplifies the setting of the control and accounts for an exceptionally wide welding range as to types of work, welding conditions, sizes of electrodes and thicknesses of material. Being continuous, the control can be advanced or retarded in increments as fine as desired.

Other features of this new line of welders include: a self-protected motor on all a-c. motor driven welders which is said to permit sustained operation with large sized electrodes at high average welding currents without danger of burnout.

Separate excitation of the welding generator in all types of these new welders provides the generator with a constant source of excitation which

The controls for the new arc welder can be advanced or retarded in increments as fine as desired.



FARREL ROLL GRINDERS

Have Smooth, Vibrationless Carriage Traverse

An important factor in grinding rolls to the accuracy and finish demanded by modern rolling mill practice is the smooth, positive traverse, steadiness of travel and the smoothly accurate reverse of the carriage carrying the grinding wheel.

In the Farrel Heavy Duty Roll Grinder this is assured by the improved design of carriage drive. The carriage is driven by a reversing motor through accurately generated Farrel-Sykes continuous tooth herringbone gears and a worm reduction to a worm meshing with the rack on the bed, the smoothest type of mechanical drive known for machine tool carriages. The gears are mounted in anti-friction bearings.

Reversal of the carriage traverse is accomplished electrically, eliminating mechanical reversing clutches. A variable speed motor and a two-speed drive provide a wide, variable speed range for every grinding condition. Speed change and point of reversal of the carriage are automatic and require no further attention on the part of the operator. Oil bath lubrication is provided for the gears and bearings of the carriage drive and for the worm meshing with the rack on the bed.

The low-cost, high-output, high-accuracy performance of Farrel Heavy Duty Roll Grinders is the result of a combination of design features which are fully described in Bulletin No. 111. A copy will be sent free on request.

FARREL

FARREL-BIRMINGHAM COMPANY, Inc.
ANSONIA, CONN.
New York • Buffalo • Pittsburgh • Akron • Chicago • Los Angeles

is independent of conditions at the welding arc. It is claimed that this aids in the maintenance of a steady arc for minimum spatter. Also, in the case of the engine driven welders, it permits the use of an over-size exciter for operation of lights and tools at slight additional cost.

A laminated magnetic circuit is employed in all types of welders providing minimum reluctance to the flow of magnetic flux. It is claimed that this construction quickens the response of the welding generator to changing arc conditions, resulting in greater arc stability and wider welding range.

This new line of welders is available in a-c. and d-c. motor driven types, belted or coupled type, and in gasoline engine and diesel engine driven types, in all standard ratings.

TORQUE MOTOR OPERATES BRAKE FOR A-C SERVICE

▲ A new torque motor operated brake for alternating current service on cranes, hoists, elevators, and similar installations has been put on the market by Cutler-Hammer, Inc. This new brake is designed especially for those applications where positive, quick, cushioned braking is required for stopping or holding a load. A sturdy, dependable torque motor, operating through a simple anti-friction ball jack, releases the brake.

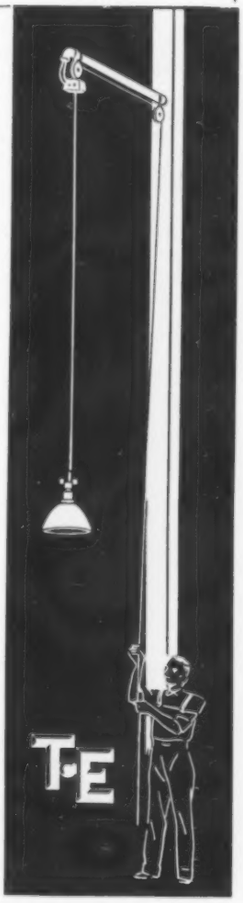
This new brake is designed especially for cushioned braking.

When the brake is fully released, the torque motor is stalled across the line. When the circuit is opened, the heavy, helical torque spring sets the brake. A slight flywheel action of the rotor provides smooth, cushioned braking.

Some of the advantages of this new brake are given as follows:

1. Smooth, quiet, efficient operation on alternating current;
2. Large lining area resulting in low unit area pressure and longer lining life;
3. Individual shoe adjustment to compensate for wear;
4. Adjustable torque;
5. Hardened manganese nickel wheel gives true braking surfaces;
6. Hardened steel pins and bushings;

Down Come Accidents
with **THOMPSON**
lamp lowering hangers



Whenever a workman leaves the ground to clean or relamp a lighting fixture, a double hazard is created—the hazard of falling and the electrical hazard.

In thousands of places, indoors and out, Thompson Lamp Lowering Hangers have eliminated this double danger and at the same time make it possible to do a better cleaning job, more cheaply. One large company realized a saving of 70%, at the same time improving its lighting and removing a dangerous hazard.

Why not ask a Thompson representative for a demonstration in your plant?

Longer Lamp Life

Is vibration or shock shortening the life of your lamp bulbs? If so, let us tell you how others have overcome this by the use of Thompson Lamp Shock Absorbers . . . lengthening lamp life as much as 500%. Inexpensive; easy to install; long trouble-free life.

Thompson Products are sold through electrical distributors

THE THOMPSON ELECTRIC CO.

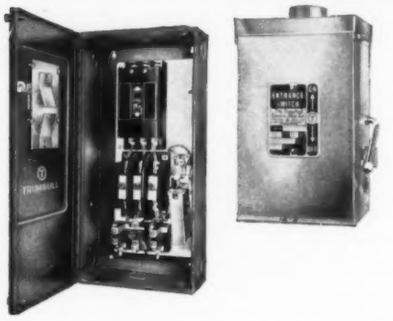
1101 POWER AVE., N. E. CLEVELAND, O.

7. Arranged for easy accessibility and maintenance.

This new brake is available in five sizes, providing maximum torque ratings of 160, 400, 800, 1600, and 3200 pounds feet on intermittent duty. Continuous duty ratings are slightly lower. They are all available for all commercial frequencies and voltages.

NEW CONTROL UNITS FOR INDUSTRIAL PLANTS

▲ Two new pieces of equipment have been recently added to the Trumbull Electric Manufacturing Company's line of industrial controls. The first is the addition of a combination magnetic starter and circuit breaker. This device is available in the range of 0 to 25 horsepower control at 110-550 volts alternating current.



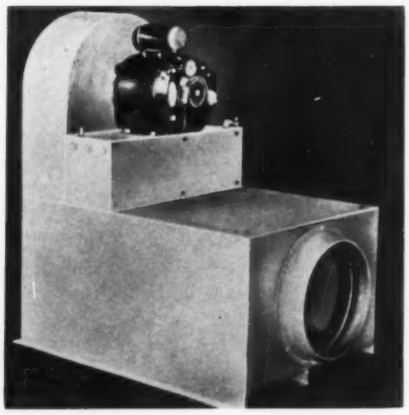
A combination magnetic starter and circuit breaker is shown at the right, and on the left is a rain-tight enclosed switch.

The second addition is a raintight enclosed switch, Type "D", 30-200 ampere, fusible. This unit is especially applicable for outside lighting installation. It is furnished in aluminum finish both inside and out making an easy-to-wire, neat appearing device.

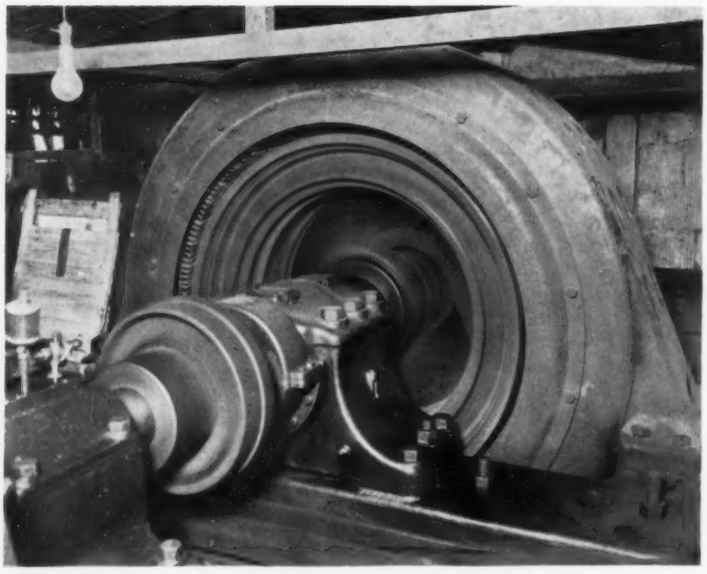
CRANE CABS AND PULPITS AIR-CONDITIONED BY UNIT

▲ Equipped with the Lintern Corporation's Type BL units, crane cabs, mill pulpits, operating stands, isolated offices and similar places in mill and factory provide year round comfort, increasing the efficiency and safety of the personnel. Features of these year round serviceable units include effective heating and rapid air circulation in winter, with twice the amount of air available in the same compact unit, for summer ventilation and cooling.

This year-round conditioning unit is capable of giving effective heating for winter, and ventilation and cooling in the summer.



Here's another big rolling mill problem



. . . successfully solved by DOLPH

At the plant of a prominent New Jersey rolling mill, the main drive motor was showing a low insulation resistance. This drive consists of two units in cascade. One is a 600 HP 4150 volt unit, the other is a 500 HP motor with slip ring speed control. These motors were too large to put into a baking oven so an air drying varnish had to be used. Due to its size and heavy loading, a flexible varnish was also demanded. After consultation with DOLPH technicians, DOLPH'S ND-17 Black Oilproof Air Drying Varnish was selected. The unit was treated with this material and returned to service in 1937. It has been in constant operation since that date and has shown no signs of failure even though it is continuously subjected to temporary overloads of 41%. The insulation resistance is now consistently high.
This is just another example of the ability of DOLPH'S Insulating Varnishes to keep motorized equipment on the job even under the most strenuous operating conditions.

JOHN C. DOLPH CO.

Insulation Specialists

166A Emmett Street Newark, N. J.

Adapted for filter attachment, a duct can be connected from blower inlet to a source of fresh air. Direction of air from heater outlet to any desired point is an additional feature, so that a maximum heating effect is obtained from a minimum current consumption. Available in three models that provide flexibility in air volume and wattage rating, all equipped with protective equipment against overheating, short circuits and motor failures, there is a unit available for any requirement. Completely air insulated, it can be located in any convenient place.

INKLESS RECORDERS FOR OUTDOOR AND INDOOR USE

▲ Continuous accurate operation for 30 days without attention, at temperatures as low as -10 degrees F. and as high as 120 degrees F., is made possible by the new Type CF-1 line of inkless recording single- and double-range a-c. ammeters and voltmeters just announced by the General Electric Company. The units are in the low-price range and are particularly well suited for voltage surveys, complaint investigations, and checking circuit load conditions. The inkless mechanism, which uses a typewriter ribbon, to make the record by a series of dots, results in greater simplicity, small size, and lightweight. There is no inkwell to clean, no pen to start, and nothing to freeze in cold weather. A cast aluminum alloy case of modernistic design protects the mechanism and further suits the new instruments for service while exposed to the weather. Although they are portable, the new instruments may be wall- or pole-mounted.

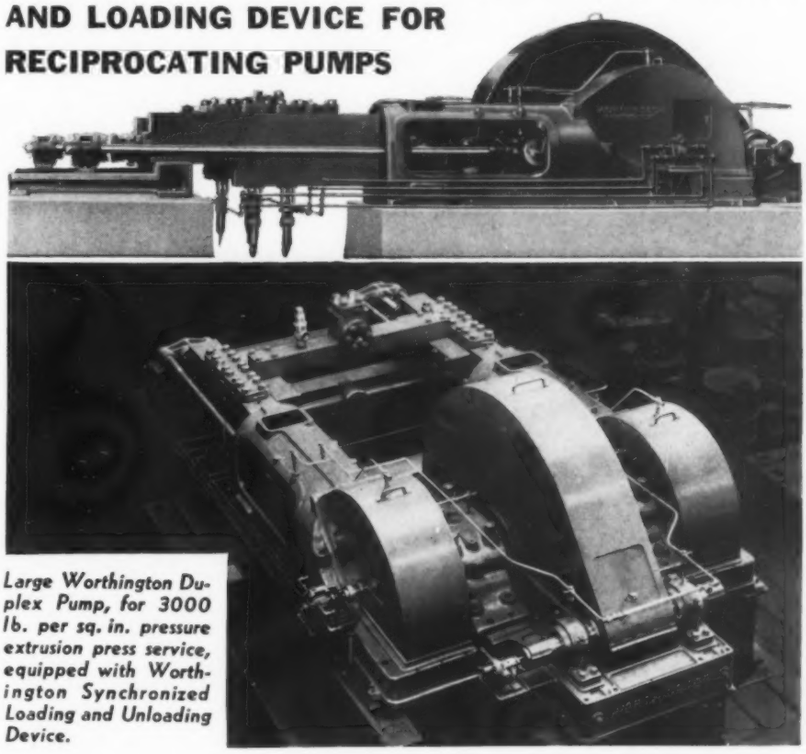
Voltmeters are listed for the double range of 0-140/0-280 volts. Ammeters are for 0-5/0-10 amperes. Single range instruments can be supplied. The voltmeter is accurate to within 1½ per cent of full-scale value over the scale range normally used; that is, 110 to 130 and 220 to 260 volts, and to 3 per cent outside those limits. Ammeters are accurate to within 3 per cent of full-scale value. The recorders have a net weight of only 11 pounds and are 10$\frac{9}{16}$ inches high by 8$\frac{9}{16}$ inches wide by 5$\frac{31}{32}$ inches deep. The chart is 4 inches wide (3½ inches record space) and is driven by a Telechron motor at 1, 2, or 3 inches per hour. A second motor of the same make operates the inkless mechanism. The new line imposes an exceptionally low burden on instrument transformers—only 1 volt-ampere for the 5-ampere ammeter or the 140-volt voltmeter at 60 cycles.

GREASE LUBRICATION FOR CRANES AND AUXILIARIES

▲ Blaw-Knox Company, through its Gordon Lubricators Division, has a new line of grease lubricating equipment for users of cranes and auxiliary equipment. Known as the Model H lubricating system, this equipment contains a manually operated pumping unit designed for use with the new

(*Please turn to page 82*)

WORTHINGTON SYNCHRONIZED UNLOADING AND LOADING DEVICE FOR RECIPROCATING PUMPS



Large Worthington Duplex Pump, for 3000 lb. per sq. in. pressure extrusion press service, equipped with Worthington Synchronized Loading and Unloading Device.

THIS device, as illustrated above on a horizontal duplex double-acting pump, establishes a new standard of design for the automatic control of high-pressure pumps. It involves a control for motor-driven power pumps which, when operating continuously and at constant speed, may be briefly defined as follows:

MEMBER HYDRAULIC INSTITUTE U.S.A.

SYNCHRONIZED UNLOADING . . . A quick but gradual decelerating fluid delivery, from full to zero flow, in not more than one-half revolution of the pump.

SYNCHRONIZED LOADING . . . A quick but gradual accelerating fluid delivery, from zero to full flow, in not more than one-half revolution of the pump.

• *Literature available*

PP9-2

WORTHINGTON PUMP AND MACHINERY CORPORATION

General Offices: HARRISON, NEW JERSEY

100 Years of Service

"A Compressor motor gave us plenty of trouble

Says: —*Max Romonoff, Manager, Romonoff Electric Co., Toledo, Ohio.* "When we installed a switch and service for the air conditioning equipment in one of the F. W. Woolworth Company's Toledo stores, we found a 50 h.p., 220 volt reduced voltage start motor on the compressor. The heavy starting current on this motor gave us plenty trouble until we installed BUSS SUPER-LAG fuses.

Their long time-lag kept them from blowing when the motor started—and our needless shutdown troubles were over."

You Too, Can Reduce Needless Interruptions

Needless opening of fuses can generally be traced to one of two causes: a fuse-case design that permits the development of poor contact heating or a fuse-link design that doesn't give sufficient time-lag.

Years of engineering research and field and laboratory tests have produced in BUSS Super-Lag fuses a design that practically eliminates all needless opening from either of these causes.

Hence users of BUSS fuses enjoy a freedom from needless interruptions not possible with any other fuse.

Since this means a saving in time and money to your company, why not start today to specify BUSS Super-Lag fuses for all your fuse needs?

And if you would like to have a more complete picture of the details of BUSS construction so that you can show others just why BUSS fuses are suited to the particular needs of your plant, let us send you a copy of the RB book on fuses.

It shows, in quick reading style, how the design of the BUSS fuse can help you abolish senseless shutdowns in your plant. A line from you will bring a copy by return mail.

BUSSMANN MFG. CO. • ST. LOUIS, MO.

UNIVERSITY AT JEFFERSON

Division of McGraw Electric Company

in a Woolworth Store *until we installed* . . . BUSS FUSES !

BUSS Super-Lag FUSES

Model H measuring valve. The pump holds eight pounds of grease and can be filled by hand or by a portable grease pump. Double acting pistons reduce time cycle of operation, and a detachable handle is a safety precaution against tampering or excessive operation.

The new valve operates on a simple displacement principle. Line pressure from the pumping unit is utilized in forcing a measured shot of grease into the bearing. When pressure is relieved at the pump, valves recharge in readiness for the next greasing cycle. Each valve has an indicator which shows when grease is delivered. This system provides independent operation of all valves in parallel. While centrally motivated, each valve is adjustable as to quantity of grease, being capable of feeding from 0 to 0.4 ounce per shot.

CONTINUOUS STRIP MILL TO BE BUILT IN CANADA

▲ Steel Company of Canada, Ltd., Hamilton, Ontario, by recent action of stockholders, has authorized directors to raise capital for construction of a continuous strip mill, to cost about $10,000,000 by issuing bonds, debentures or other securities. This will be the first continuous mill in Canada and one of the few outside the United States. One was completed recently for the Richard Thomas Company, Ebbw Vale, England.

In preparation for this development, the Steel Company of Canada in 1937 purchased from the United Engineering and Foundry Company, Pittsburgh, Pennsylvania, a 44-inch blooming mill, a duplicate of the new blooming mill of the Republic Steel Corporation, Cleveland, Ohio, and of the Richard Thomas and Company at Ebbw Vale, England.

NEW LITERATURE

▲ Westinghouse Electric and Manufacturing Company, located at East Pittsburgh, Pennsylvania, has announced the following new catalogues and booklets now available for distribution:

Descriptive data 3610—Westinghouse gear motors, self-contained drives consisting of a high speed motor and necessary speed reducing unit.

Descriptive data 3620—Types SH and DH speed reducers, used with all prime movers such as electric motors and gas, oil or diesel engines, and suitable for any application where economy of power transmission and exact speed reduction are important.

Bulletin B-2159—Adaptations and developments of all types of geared drives. Single, double and triple reduction gearmotors; single and double reduction speed reducers; special vertical and right angle vertical geared drives; single and double reduction heavy duty mill units; horizontal speed reducers with shafts in vertical plane; geared drives for special problems and conditions; and open gearing are discussed.

Catalogue Section 47-230—Type LR feeder-voltage four-step booster-regulator, particularly applicable to conditions where load changes over a wide range cause considerable fluctuation in voltage as well as low voltage during heavy-load periods. The standard booster-regulator is of the outdoor type arranged for either pole or platform mounting. It provides a boost of ten per cent in two and a half per cent steps or a buck in the same steps during periods of high voltage.

Bulletin B-2170—Multiple retort stokers for boilers from 300 rated boiler horsepower up, of four types, continuous ash discharge stokers with link-grate action, clinker-grinder stokers with link-grate action, dump grate stokers with agitator, dump grate stokers; and single retort stokers for boilers from 100 to 500 rated boiler horsepower, in moving or stationary grate types.

Bulletin B-2131—The arc quencher, dividing and extinguishing the arc almost instantly, eliminates flashover, assuring safety for the operator, and the high overload capacity results in unlimited life of arc box and contacts. Banishing of arc hazard permits a snugly built, compact mechanism retaining ample wiring space and complete accessibility of all parts.

▲ Mathews Conveyer Company, Ellwood City, Pennsylvania, has revised their book on, "Natural Laws Applied to Production". The text deals with a basic principle of production and covers the field of mechanical handling. It shows how modern industrial organization is based on the principle of continuous flow.

Interested readers of the IRON AND STEEL ENGINEER are especially invited to write for a copy of this book, which has been designed for use in private libraries.

▲ De Laval Steam Turbine Company has recently issued a new booklet on rotary displacement pumps for handling fuel and crude oils, lubricating oils and hydraulic oil. The rotary displacement pump has only three moving parts, a power rotor and two sealing rotors, which carry helical teeth that mate as they roll to form fluid-tight enclosures traveling continuously from suction to discharge, resulting in steady delivery without pulsation. There are no reciprocating parts, valves, timing gears, or separate bearings, and only one stuffing box, which is under suction pressure. The pumps can be directly coupled to steam turbines or electric motors and are adapted to all capacities and pressures.

Anyone who is interested in receiving this booklet should write to the De Laval Steam Turbine Company, Trenton, New Jersey.

Leeds and Northrup Company has issued a bulletin describing a new switchboard model temperature indicator. This new indicator allows ample space for toggle-type switches, for connecting any one of a number of couples to the measuring circuit. Installed wherever convenient, it enables an operator to measure temperatures of near or distant couples with equal reliability, by simply turning a knob, until a pointer comes to zero, and reading a temperature scale.

Catalogue N-33A (5) may be obtained by writing to the Leeds and Northrup Company, 4901 Stenton Avenue, Philadelphia, Pennsylvania.

▲ Foster Wheeler Corporation has available for distribution a catalogue which describes an all-welded, all-steel, packless expansion joint. The flexible element in this joint consists of a stainless steel bellows. This joint is essentially foolproof, in that it involves no adjustments or lubrication by an operator, and is a single welded construction from end to end. Materials are of forged and rolled steel especially selected and fabricated for the services involved.

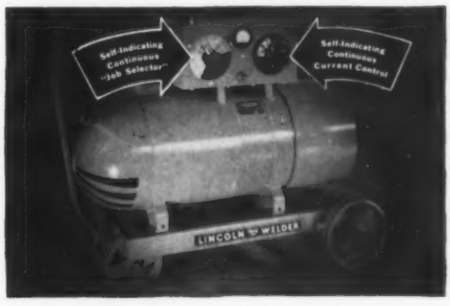
The Foster Wheeler Corporation is located at 165 Broadway, New York, New York.

PLUGGING FOR PROGRESS WITH POP AND LAD

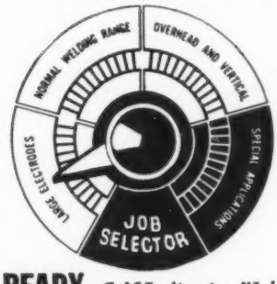
BIG GAME THAT'S ALWAYS IN SEASON

How to bag it with the New "Shield-Arc"

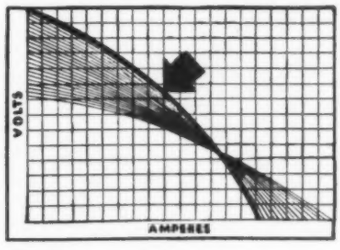
TYPICAL HUNTING GROUND
Flat, downhand welding of machine bases with 3/8-inch electrode.



THE WEAPON. New *"Shield-Arc"* with Self-Indicating "Job Selector" and Current Control.



READY. Self-Indicating "Job Selector" sets "sights" of *"Shield-Arc"* Welder for accurately aimed volt-ampere curve.



AIM. At this setting, volt-ampere curve has steep slope. Hence, changes in arc length have little effect on welding current, assuring steady arc heat at high deposit rates.

FIRE! Molten metal flows at maximum speed and with minimum spatter because arc is high-powered, yet steady. Result: Lowest cost-per-pound-deposited is *in the bag.*

"I know a user of this new Lincoln who was able to boost his electrode calibre from 5/16" to 3/8" and . . . wham! . . . cost-per-pound-deposited dropped from 75c to 55c. At 5 lbs. per hour, that's a buck bagged every hour throughout a perpetual season!"

"Right, Pop. This 'Shield-Arc' is the answer to many profit-hunters' prayers because it provides *any* TYPE of arc and *any* AMPERAGE—each one labeled. Your hunting domain is bigger and richer. Shoot the coupon for your free guide."

Largest Manufacturers of Arc Welding Equipment in the World

THE LINCOLN ELECTRIC COMPANY
CLEVELAND, OHIO

THE LINCOLN ELECTRIC CO., Dept. Z -567, Cleveland, O.
Send free copy of Bulletin 412-A.

Name _____ Position _____
Company _____
Address _____
City _____ State _____

ITEMS OF INTEREST

C. H. Saiter
has been appointed sales manager of the heavy crane division, Cleveland Crane and Engineering Company, with headquarters at Wickliffe, Ohio. Mr. Saiter was born in Marion, Ohio. He was with the Morgan Engineering Company for ten years before going to the Cleveland Crane and Engineering Company in 1922. He served as assistant chief engineer of this company for a number of years prior to being appointed manager of the Pittsburgh district in 1931. Mr. Saiter, who has been an associate member of the Association of Iron and Steel Engineers for many years, will for the present continue to actively supervise the Pittsburgh district in addition to his new duties. H. T. Florence, who has been sales manager, was recently appointed general manager of the company.

C. H. SAITER

L. M. Kirk
has been appointed superintendent of mold preparation in the open hearth and central mills division of the Carnegie-Illinois Steel Corporation, Gary, Indiana. Mr. Kirk's experience in the steel industry began in 1927, when he was employed as assistant master mechanic at the Johnstown plant of the Bethlehem Steel Company. After serving there in various capacities until 1936, he went to the Worth Steel Company as assistant open hearth superintendent. He remained with this company until his employment at the Gary Works at this time.

S. B. Heppenstall, Jr.
was recently made vice president and general sales manager of the Heppenstall Company, Pittsburgh, Pennsylvania. Mr. Heppenstall was educated at the Pennsylvania State College, and joined the company in 1928. Until recently he was the assistant sales manager.

Other changes in the Heppenstall Company are as follows: C. W. Heppenstall as chairman of the board of directors; C. W. Heppenstall, Jr., as vice-president in charge of operations; R. B. Heppenstall as president; and G. F. Ritenbaugh was made secretary and treasurer. This year marks the fiftieth anniversary of the business which was founded as the Tretheway Manufacturing Company in 1889.

William A. Marshall
has been appointed superintendent of maintenance, Carnegie-Illinois Steel Corporation, Irvin, Pennsylvania. Mr. Marshall, a graduate of Pennsylvania State College, was resident engineer at the Vandergrift Works from March, 1935 to June, 1937. Prior to that time he was successively assistant master mechanic and master mechanic at Farrell Works, and from August, 1932 to March, 1935 he was master mechanic at the Farrell-Mercer Works. In June, 1937, Mr. Marshall was appointed superintendent of construction at the new Irvin Works, the position he held until the present time.

Other appointments at the Irvin Works are as follows:

Warren W. Scherer
as assistant superintendent of maintenance; and,

Arthur M. Krieger
as assistant to superintendent of maintenance.

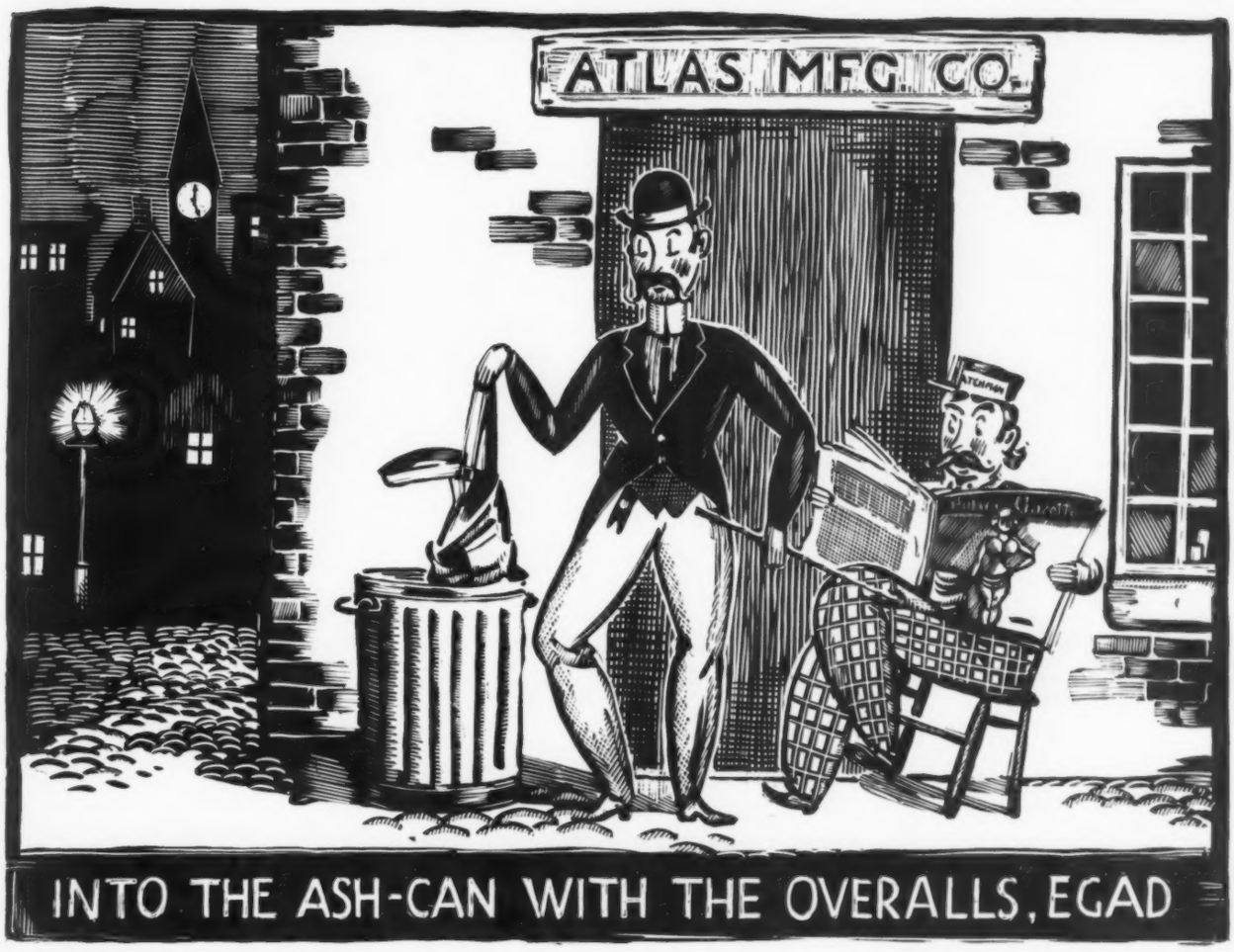
L. R. Kells
has been appointed chief engineer for the Salem Engineering Company, of Salem, Ohio. Mr. Kells graduated from Ohio State University in 1914,

L. R. KELLS

and has been intimately associated with the industrial furnace industry for over twenty years.

W. R. Swoish
was appointed sales manager of the Roller-Smith Company, with headquarters at Bethlehem, Pennsylvania. Mr. Swoish, formerly with the Westinghouse Electric and Manufacturing Company, has had a varied experience since his graduation from Ohio State University in 1921. Until his recent affiliation Mr. Swoish held several managerial posts with the Westinghouse Company, chiefly in the switchgear division.

W. P. Schmitter
has been appointed chief engineer of the Falk Corporation, Milwaukee,



TIME was when Elmer was only a helper, but they made him Chief Electrician today! If asked for the secret of his success he would probably tell you that he cleaned up his wire-wrecking hot spots and reduced maintenance expense by taking advantage of the "Ten Tested Rockbestos Values."

Don't envy Elmer—just follow his example and you'll be stringing along with the many electrical maintenance men who put their stamp of approval on our ten tested values in response to a recent questionnaire. To quote a few: "We rewired circuits in a steam tunnel every two years before installing Rockbestos." . . . "I have specified Rockbestos A.V.C. to withstand heat in our power plant boiler room." . . . "The only wire that ever gave reliable service under excessive heat and moisture." These comments are typical of many from satisfied Rockbestos users who want dependable circuits at lower cost.

TEN TESTED ROCKBESTOS VALUES

1. Heatproof
2. Fireproof
3. Permanent
4. Lower maintenance cost
5. Resists heat and vibration
6. Saves work
7. Oil and Greaseproof
8. High overload capacity
9. Permanently flexible
10. Greater carrying capacity

Check all ten tested money-saving values against your plant conditions and order Rockbestos for locations in which needed. For samples or catalog, write Rockbestos Products Corp., 912 Nicoll Street, New Haven, Conn.

Also refer to Electrical World Buyer's Reference

ROCKBESTOS A.V.C.—the wire with permanent insulation

Wisconsin. Other appointments are as follows: Louis W. Falk becomes executive engineer; and Harold S. Falk, vice-president, continues in his present capacity as director of engineering.

W. J. Ramsey has been appointed field engineer for the Mathews Conveyer Company, with headquarters at Philadelphia, Pennsylvania. Mr. Ramsey was born May 23, 1899, in West Chester, Pennsylvania. He was educated in the Philadelphia public schools, and received a mechanical engineering education at Franklin Institute and Drexel Institute. In 1919 he went with the Baldwin Locomotive Works, Philadelphia, Pennsylvania, where he was employed as a draftsman until 1923. In that year he went with the Haslett Chute and Conveyor Company, Oaks, Pennsylvania, successively holding the positions of draftsman, chief draftsman, estimating, and field supervision. In 1929 Mr. Ramsey joined the Mathews Conveyer Company, Ellwood City, Pennsylvania, as a proposition engineer, designing conveying equipment and systems. He was then associated in the research department chiefly concerned with new development and engineering data. In 1931 he became manager of advertising and sales promotion holding that position until the present change which is effective March 1, 1939.

W. J. RAMSEY

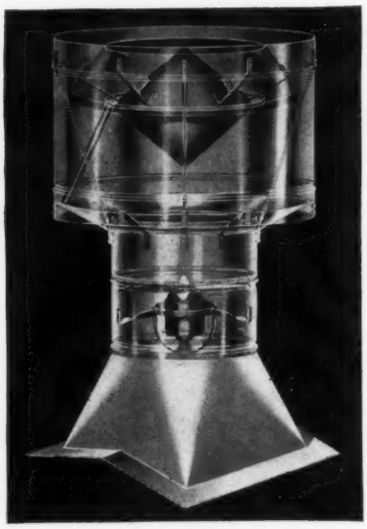
Henry E. Helling, Jr. will succeed Mr. Ramsey as advertising manager for the Mathews Conveyer Company, Ellwood City, Pennsylvania. Mr. Helling has been assistant advertising manager.

OBITUARY

E. S. Simkins died recently in his fifty-sixth year. Mr. Simkins was graduated from the University of Pennsylvania in 1906, after attending Drexel Institute. He started his business career with the Pennsylvania Railroad's engineering corps, and later went with the New York Telephone Company. After spending a year in Costa Rica with a mining company, Mr. Simkins returned to the United States where he entered the employ of Standard Underground Cable Company in 1912, working continuously in the Pittsburgh and Cleveland territories until 1929. Leaving the Standard Underground Cable Company, now the General Cable Corporation, he became affiliated with the Anaconda Wire and Cable Company, located in New York and Chicago. Prior to his death, Mr. Simkins had been in the insurance business.

BURT Free-Flow Fan VENTILATORS

. . . RUGGED
. . EFFICIENT
. DEPENDABLE



The Burt Free-Flow Fan Ventilator line was designed specifically for heavy-duty industrial applications. Sizes range from 12-inch to 96-inch, with free air deliveries from 1200 cfm to over 100,000 cfm.

Motor protection from high ambient temperatures is provided in heat-resisting construction; and from corrosive vapors in acid-resisting construction.

The use of these units in many modern steel mills and other heavy industrial construction projects has definitely proven their ruggedness, efficiency and dependability.

Investigate these ventilators for any projected expansion or modernization projects you may have. Detailed data, job references and engineering assistance will be furnished promptly.

The BURT Manufacturing Co.

ROOF VENTILATORS — OIL FILTERS

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